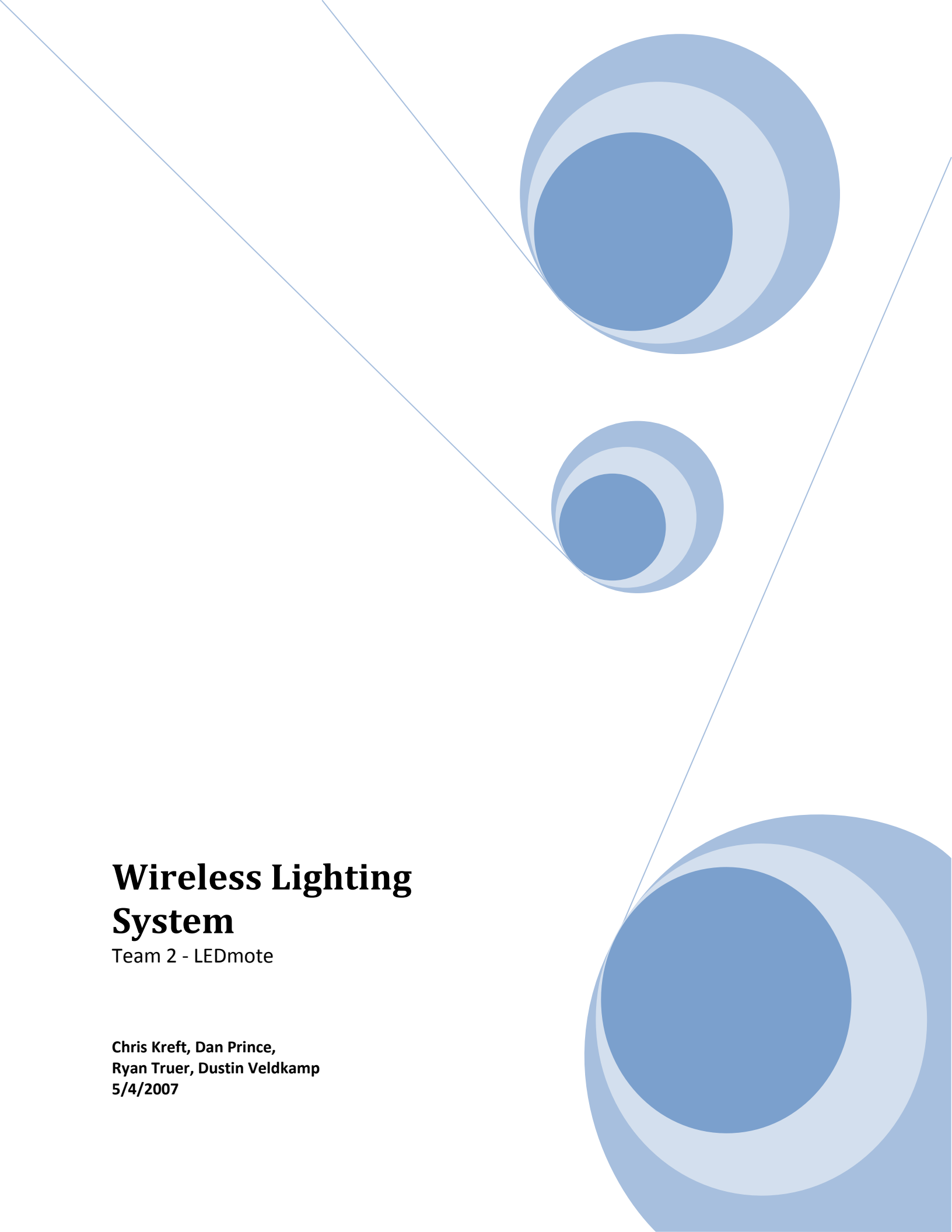

Wireless Lighting System

Team 2 - LEDmote

Chris Kreft, Dan Prince,
Ryan Truer, Dustin Veldkamp
5/4/2007

Abstract

The following report documents the work of Team 2 – LEDmote, a group of students from Calvin College working with Innotec Corp. The team designed and prototyped a wirelessly controlled lighting system during the 2006-2007 school year. The system uses multicolor LED lights and can be implemented for office, entertainment or home use. At the end of the project, a collaboration of materials and documentation was passed on to Innotec as a model for development of one of their projected commercial products.

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1 Introduction

1.1 The Project

Team LEDmote designed and prototyped a wirelessly controlled lighting system using multicolor LED lights. This lighting system was designed with flexibility in mind, so that it can be marketed in a variety of applications including conference room, theater and home lighting. Wireless control was designed to be available through a remote control device and also via computer software which could be loaded either onto a wireless-compatible laptop brought into a room or onto a wirelessly-compatible local desktop computer located in the room. The lighting system provided a range of color options to the user and provided a variety of settings for light intensity. The lighting system can be implemented by using a number of light fixtures, distributed throughout a room.

1.2 Innotec

Project LEDmote was supported by Innotec Corporation located in Zeeland, MI. Innotec is a growing company that designs and builds automated systems for the automobile industry. Innotec and its six satellite companies currently employ about 450 people. The company chiefly operates in the West Michigan area, but has recently expanded globally, opening manufacturing plants in Hungary, China and Mexico. They are branching out into other industries, especially in the LED industry.

Innotec wanted to build a lighting system based on the prototype lamp module design created by team LEDmote. This lighting system would then be sold at profit on the market. Innotec supplied funding for the prototype and assistance in providing requirements and project objectives. In addition, Innotec allowed Team LEDmote to use their soldering facilities and resources in project development. Our project has provided them with a design analysis report, a prototype, and a business analysis which they can use to potentially develop into a final product.

1.3 Mentor

Tom Veenstra, an employee of Innotec, was the mentor for this project. Mr. Veenstra is a graduate of the Calvin College Engineering program with a concentration in electrical engineering. He currently leads R&D in the Innotec lighting division. He was instrumental in providing requirements and advice for the design team. He was the team's chief liaison with Innotec.

1.4 The LEDmote Team

Team LEDmote was comprised of Chris Kreft, Dan Prince, Ryan Truer and Dustin Veldkamp.

Chris Kreft was born in Philadelphia, Pennsylvania to Zimbabwean parents who returned home when he was two years old. He attended Gateway Primary and High Schools located in Harare, Zimbabwe before immigrating with his parents to the United Kingdom. In 2002, he chose to continue his education at Calvin College after discovering his interest in learning about the country of his birth and hearing a call from God. He hopes to use his skills to one day work in International Development back on his home continent. Chris currently works for Apex Controls in Hudsonville, Michigan and will work for them as a fulltime Controls Engineer once he graduates in May 2007.

Dan Prince was born in Shelby, Michigan and was raised in New Era, Michigan. He went to New Era Christian School for his education from Preschool to the eighth grade. His high school education took place at Western Michigan Christian High School in Muskegon. Following his senior year of high school, he moved to Grand Rapids and began his freshman year at Calvin College, starting in the engineering program. At the conclusion of his second year at Calvin, he chose an electrical and computer engineering concentration because of a growing affinity towards computers and electronics. He is now in his fourth year at Calvin and will graduate in May of 2007 with a bachelor's degree of science in engineering. He currently works for GE Aerospace and is planning to attend graduate school at the University of Michigan in the Fall of 2007.

Ryan Truer was born and raised in Grand Rapids, Michigan. He attended Sylvan Christian School from pre-school to eighth grade and after that obtained a high school education at Grand Rapids Christian High School. After high school he chose to attend Calvin College for a pre-architecture degree. After a year he switched into the electrical and computer engineering program. Ryan is currently in his fifth year at Calvin and plans to graduate in May 2007. He currently serves as an intern at Beta Integrated Concepts and also grades and lab assists for a microelectronics class. He plans to work for Alticor after graduation.

Dustin Veldkamp was born and raised in southwest Minnesota. He brought business background, education and experience to the group. He graduates in May 2007 from Calvin College with degrees in Business and Engineering. Dustin worked with Tom Veenstra and was the team's main liaison with the company. He plans to work for Gentex once he graduates.

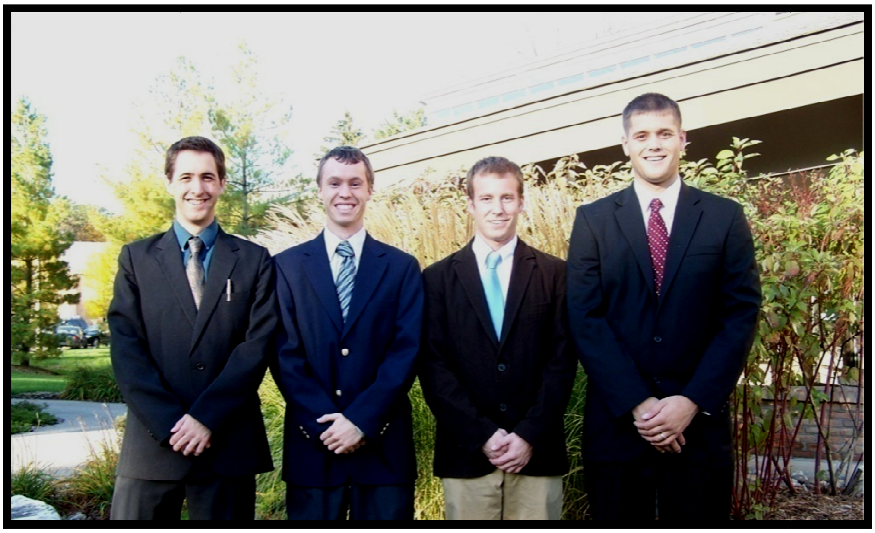

Figure 1 - Team LEDmote

1.5 Engineering 339 and 340

Engineering 339 and 340 are classes offered by Calvin College in the Fall and Spring (respectively) of each year. The classes are collectively called "Senior Design" and are a unique opportunity for Calvin engineering students to get hands-on experience with a real engineering project under the supervision of four engineering professors – one from each of the four engineering concentrations offered at Calvin.

While working on their projects, the team members also receive instruction in using Christian design norms to influence their design, career development and job seeking, ethics and team building.

2 Terms

Table 1 - Terms

ENGR	Engineering
FFD	Full Function Device (Zigbee)
FPGA	Field Programmable Gate Array
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
LED	Light Emitting Diode
MCU	Microcontroller Unit
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
OS	Operating System
PC	Personal Computer
PCB	Printed Circuit Board
PIC	Microcontroller Developed by Microchip Technology
PPFS	Project Proposal and Feasibility Study
PWM	Pulse Width Modulation
RFD	Restricted Function Device (Zigbee)
RGB	Red Green Blue
SPI	Serial Port Interface
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
VAC	Volts Alternating Current
VDC	Volts Direct Current

3 Project Scope

In an engineering project, it is critical to accurately spell out the scope of the project. This both sets the expectations for the group and keeps the group united with one common focus. With guidance provided by the scope, the team made key decisions steering the progress of the project throughout the course of the semester. During each major decision, the project requirements were consulted to determine which path was most directed towards the requirements.

3.1 The Challenge

3.1.1 Scope of Hardware

3.1.1.1 MCU

The PIC Microcontroller Unit (MCU) in the lamp base was meant to coordinate between the Zigbee controller and the Bluetooth controller and also manage the lights. The original plan was that a master

lamp would contain both Bluetooth and Zigbee wireless controllers; whereas all secondary lamps would contain only Zigbee wireless controllers.

3.1.1.2 Bluetooth

The Bluetooth protocol was chosen for its functionality and marketability. Bluetooth is functional, because the wireless signals transmitted by a Bluetooth transceiver are not fixed to one frequency. The signals "hop" around on varying frequencies at very high speeds to prevent interference with other signals. This allows the lighting system to utilize two 2.4GHz wireless protocols. The Zigbee protocol will be fixed to one frequency, while the Bluetooth protocol will "hop" around avoiding interference with Zigbee.

Bluetooth is marketable simply because it is common in many devices already on the shelf. Most new computers and laptops have a Bluetooth transceiver and many handheld devices do as well. If a customer's device did not have Bluetooth, it would be easy to purchase a USB plug-in module that could communicate with this lighting system. If the Zigbee protocol were to be used as the sole wireless transmission method, most customers would have no method of connecting to the lamps except by the remote control. This would resulted in limited control of the lamp system.

3.1.1.3 Zigbee

The Zigbee protocol was chosen to give the project increased flexibility and functionality. The Zigbee protocol has the added functionality of creating networks of transceivers. Within a Zigbee network, when a signal is sent from one transceiver it is repeated to the entire array. This means, that a remote could send a signal to one lamp and this signal would be sent to all lamps in the network. This is flexible because the remote can make its original communication with any lamp. It is functional, because networks can be used for an entire room or an entire office building. The lone requirement is that the distance between lamps can be no greater than 10 meters (33 feet).

3.1.1.4 Supporting Hardware

The supporting hardware of the system consists of an array of buttons on the remote to function as inputs, an array of tri-color LEDs to provide colored light, an array of white LEDs to provide working light, and transistors at every pulse width output to give the LEDs adequate voltage. The hardware also includes an encoder chip which functions both as a button debouncer and a transition stage from our 11-input button to our 4 interrupt ports on the development boards

3.1.2 Scope of Software

3.1.2.1 PC Software

The Personal Computer (PC) software was intended to give a user more control and functionality over lamp arrays. The original design was meant for the user to be able to select a color out of a choice of over 1,000 colors. The user could also have chosen brightness for both white and multi-colored light from a list of 12 shades. For added flexibility, the user could also change the settings of individual lamps as well. Permitting that there was adequate time for design, the software would also include a lighting schedule. With the lighting schedule feature, the user could select what color and brightness the lights

would be at any time of the day. The lights would then automatically turn to these presets at the appropriate times.

3.1.2.2 PIC program for Lamp Base

The Lamp Base PIC MCU software was intended to manage the incoming signals from both the Bluetooth and Zigbee transceivers, decode them, and change the duty cycle of the pulse width to the appropriate setting.

3.1.2.3 PIC program for Remote Control

The Remote Control PIC MCU software was intended to receive the button inputs and send out a wireless message that corresponds to the button pressed.

3.2 Design Norms

Throughout the design process, the team was concerned with how the design of the system correlated with Christian values. One way to do this was to identify the design norms that could apply to the project. Design norms are general principles that give an ethical guideline for a project and ensure that technology is truly in service of God and society.

The design norms chosen for this project were transparency, harmony and stewardship. Transparency appeared in the project in both hardware and software. In the hardware, the remote control was user-friendly, allowing a user to easily identify how to change colors, brightness and how to turn the lighting system on and off. In software, the user was able to easily identify functionality from the PC program available. The software followed conventional programming standards.

Harmony is qualified in the following sentence by Gayle Ermer, an associate professor at Calvin College: "***The design should be pleasing to use, attractive, and promote healthy relationships***". This norm, also known as integrity, was seen in the aesthetic value of the design which was fun, flexible, intriguing and easy to use.

The final design norm, stewardship was seen in the use of LED lights as opposed to incandescent bulbs. The use of LED lights minimized power consumption and removed detrimental effects on the environment that occur from excessive energy consumption. Such detrimental effects include global warming from the burning of fossil fuels and environmental damage resulting from other power generation units such as hydroelectric dams which interfere with natural water forms. In addition, LEDs do not have the toxic materials of lead and mercury that incandescent and fluorescent bulbs use, nor does a user need to be concerned with the possible dangers associated with broken glass from damaged bulbs of this type. The use of wireless technology minimized the need for wiring between light modules, and so reduced the overall system cost. Although the initial installation costs were greater, ultimately the long-term costs were minimized. Also, since LED and wireless technology are fairly recent developments, their relative costs (as compared to alternatives) are anticipated to decrease over time.

3.3 Project Requirements

3.3.1 Prototype Requirements

The original prototype called for one remote, one PC connection, and two lamps. One of the lamps was to contain both a Zigbee and Bluetooth wireless transceiver, and the other would contain a Zigbee transceiver alone. This was to demonstrate the functions of the prototype, which include a Bluetooth transfer repeated to both lamps, a Zigbee transfer repeated to both lamps, a Bluetooth transfer that changes only one lamp, functional demonstration of a remote and functional demonstration of software on a PC.

Table 2 - Prototype Requirements Check

Original Design	Final Prototype	Reason for Change
One Remote Control	One Remote Control	-
Zigbee Connection	Zigbee Connection	-
One PC Connection	Incomplete Bluetooth Connection	See Section 4.3 Original Design

3.3.2 Overview

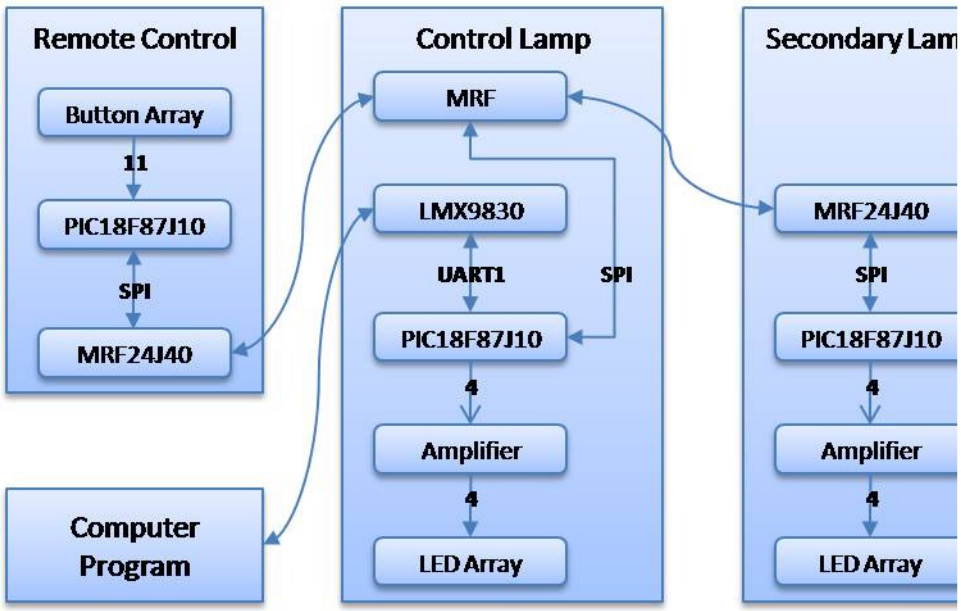

Figure 2 – Original Design Block Diagram

3.3.3 Remote Control

The remote control was designed to allow the users to communicate to any light in the room from any position he/she is standing. The remote control is a nice feature to have with this lighting system because it does not limit the user to any distance from a light, but at the same time, it was designed for limited operability of the lights.

3.3.3.1 Power Supply

The remote control was designed to use 2 AA batteries, which would produce a 4.5 V output onto the board. This was a little high because the processor and Zigbee module were specified to run at 3.3 V. To knock down the voltage to a tolerable level for the processor to handle, a REG103GA-3.3 linear voltage regulator was used. The datasheet for this regulator, states that this voltage regulator can take an input of up to 15 V. This was nice to know because it can handle the input from the batteries. On an added note, the voltage regulator can also handle an input of 12 V, which the Lamp Modules run off of. This voltage regulator is also rated at 500 mA, this is well above the current that the main processor and the Zigbee processor ever pull.

3.3.3.2 Button Array

In creating a button array for the prototype, the team aimed to create an intuitive user interface. A power button served as an on/off switch for the display lamp. Other buttons consisted of three sets of two buttons to increase or decrease the amount of red, green and blue coloration added to the emitted light from the lamps. Finally, the remote control had increment and decrement buttons for the RGB LEDs and for all the white LEDs simultaneously.

The buttons that were chosen were from ITT Industries, and had the characteristics of normally open single pole single through buttons, which can be found on the SPST Momentary Key Switches Datasheet. This allows us to connect the 3.3V line to one side of the push button and the other side to the processor, and when pushed the button would allow 3.3V to trigger the processor.

3.3.3.3 Processor

The processor that was chosen was the PIC18F87J10 made by microchip. This processor was chosen above other ones mainly because of its five pulse width modulation outputs, its two UART port modules and it ran on a common 3.3V input. As the search began for the processor, it was hard to find one with that many pwm outputs and two UART ports. When the project first began, the team was under the impression that two UARTs would be needed to connect to the Bluetooth module and the Zigbee module. This however changed along the way because it was found out that the Zigbee uses a Serial Port instead of a UART. The PIC18F87J10 was a very good processor for this project, and it was decided that it could be used in the remote control and the Lamps. The button inputs were designed to directly input into 11 different I/O Ports on the processor.

3.3.3.4 Zigbee Chip

Originally, the Freescale Semiconductor MC13192 was used. This Zigbee chip seemed to be the best chip that we could use at the time that we researched it. It was found to be able to connect to a large variety of microcontrollers through a SPI connection, which the PIC18F87J10 supports. So at the time it was assumed that the Zigbee protocol stack could have been loaded onto the PIC18F87J10. Although it was assumed that the MC13192 would be able to

work with the PIC18F87J10, it was hard to find support for doing this.
Then around January, another chip made by Microchip was released. The Zigbee Chip that was selected was the MRF24J40. There was a lot more support for this chip and Microchip has its own Zigbee Protocol Stack specifically designed for PIC18F Microcontrollers. The support for loading the stack onto a PIC18F processor can be found in the AN965: Microchip Stack for the ZigBee™ Protocol Datasheet. This chip was selected because microchip fully supports this Zigbee chip with the PIC18F87J10. This Zigbee chip was designed to connect through the SPI port on the PIC18F87J10 and was also designed to send out a clock output for the PIC18F87J10 to use.

3.3.3.5 Remote Control PCB Design

After all research was done on all of the different components that attached to processor and the Zigbee chip, a printed circuit board was created. Since the Zigbee is an RF transceiver, a lot of things had to be considered when laying out the board. The MRF24J40 Datasheet mentions everything that should be considered in the designing of a RF board. The datasheet also provided a suggested layout for the Zigbee chip, so the design that was approached was to follow Microchips design as closely as possible. The final layout is shown below in Figure 3.

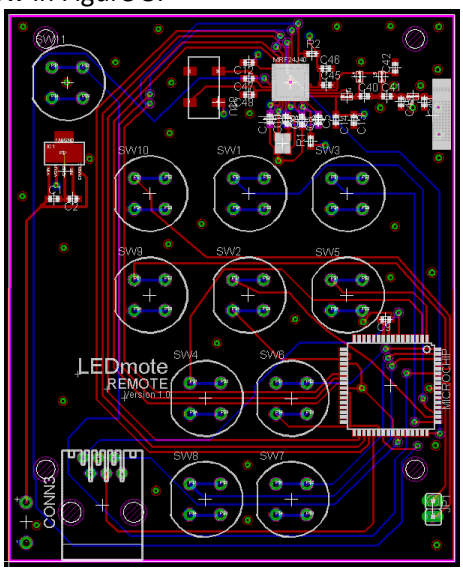

Figure 3 – Remote Control PCB Design

3.3.4 Control Lamp

3.3.4.1 Power Supply

The power supply for the lamp was designed a lot differently than in the remote control. The lamps were designed to be plugged into a 120V/60Hz or 240V/50Hz wall socket. So the first step was to send the voltage through a switch mode power supply, which would cut the voltage down to 12V DC. The power supply that was chosen was a ETS120400UTC-P5P-SZ made by CUI Inc. From the datasheet it was found that this power supply could handle currents of up to 50A. This was a little over kill because currently the LED array draws a little less than 25A. It was chosen a little high in case more LEDs were needed

in the future, which would ultimately draw more current. This power supply would then output 12V, as stated above, which would be used to drive the 12V LED array. But another step down in voltage was needed before it could be run to the microprocessors, which ran at 3.3V. To make this step down the same voltage regulator that was used in the remote control was again used.

3.3.4.2 Bluetooth Module

The Bluetooth module that was chosen was the LMX9830 Bluetooth Serial Port Module made by National Semiconductor. This Bluetooth module was chosen because it has its own processor embedded into it. With its own processor in it, the Bluetooth protocol stack does not have to be loaded onto the PIC18F87J10 like the Zigbee Stack does. Even though the price of this Bluetooth module was slightly higher because of the built in processor, it paid off because it would only be used in one lamp which would prevent the lighting system to be too expensive.

The Bluetooth module would connect to the microprocessor using a UART interface. The datasheet of the LMX9830 gives explicit directions on how the UART is set up. The UART in the LMX9830 supports a four wire connection, which operates better because it uses two recognition lines. But the LMX9830 can also connect to a two wire UART microprocessor, which the PIC18F87J10 only supports, this information can be found in the LMX9830 – Software Users Guide. It requires that the Clear To Send (CTS) input to be pulled ground. This will allow the two processors to properly talk to one another.

This Bluetooth module was used because it creates a Serial Port with another Bluetooth unit. Once it is connected as a Serial Port with another unit, the two Bluetooth units can transmit whatever data that is needed.

3.3.4.3 Amplifier Circuit

An amplifier circuit was needed because the PIC18F87J10 outputs 3.3V and the LEDs run on 12V. This would not allow the LEDs to light up properly because they would never get to the right voltage level. In order to drive the LEDs, a N-Channel MOSFET transistor was designed to step up the voltage. The transistors that were chosen were FDN339AN transistors made by Fairchild Semiconductor. The datasheet that went along with these transistors states that they can handle 20V and up to 3A. These transistors had to be rated high enough to handle the 2.3A draw from LEDs.

3.3.4.4 LED Array

The LED Array PCB can be seen in Figure 4. Using a set of four high power MOSFET transistors the current driven through each pair of LED's can be controlled. By pulse width modulating the base of each transistor the intensity of each color can be adjusted. The prototype array contains 8 RGB LEDs used to demonstrate color changes and ten white LEDs. The white LEDs are not mounted to the board in Figure 4 due to heat dissipation requirements. In order to quickly dissipate heat, the white LEDs must be mounted to a specialized heat sink surface. If mounted to the PCB, the base of the PCB will likely melt. The white LEDs were mounted directly to the display lamp metal casing to allow heat dissipation. The white LEDs are connected to the pads

shown at the top of the board. Current passes through four current-controlling resistors before passing through the LEDs. The white LEDs are paired in series so each of the first five pads shown (from left to right across the top of Figure 4) are connected in series to two white LEDs. Given the variability of the resistors and LEDs a worst case analysis was performed on this circuit to find the optimal values and tolerances for the resistors. This analysis can be seen in Appendix 10.3.

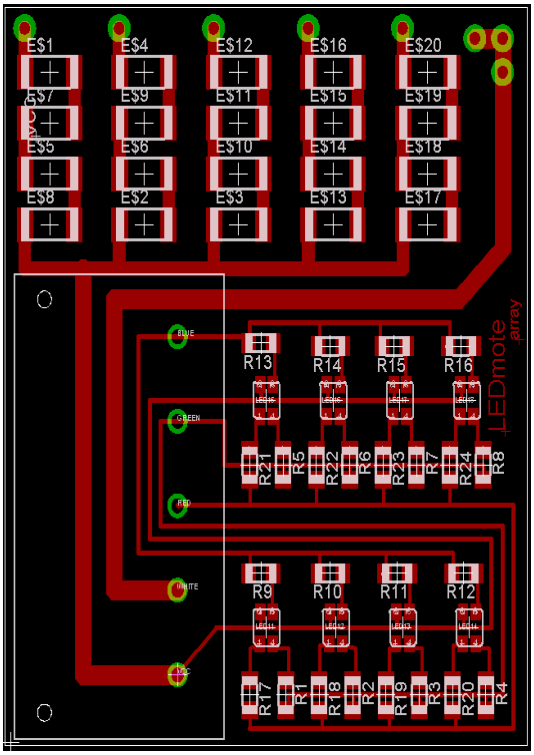

Figure 4 - LED Array

3.3.4.5 Lamp Base PCB

The lamp base printed circuit board was designed much in the same way as the remote control circuit board. With the development kit that was purchase for the LMX9830, some of the software that came with the kit provided the prints for the four layers of the development kit. These prints were replicated as close as possible just like the PIC18F87J10 and the MRF24J40 were before. Also, a bit of concern was created by the use of two RF modules on one board. The solution that was proposed by the team was to put the two RF modules as far away as possible. From Figure 5, it can be seen that the Bluetooth was populated near the top left and the MRF24J40 located at the bottom middle of the board.

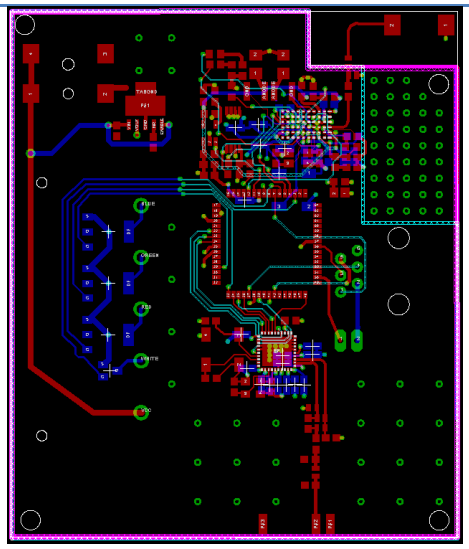

Figure 5 - Lamp Base

3.3.5 Secondary Lamps

The secondary lamps do not need any more explaining because they are basically just a striped down Control Lamp. The secondary lamps do not need a Bluetooth unit because these lamps just rely on the Zigbee modules to communicate to the rest of the lamp network.

Complications

Two Display Lamps

One Display Lamp

3.4 Limited by Development Boards, Also see Section 4.3 Original Design

3.4.1 Overview

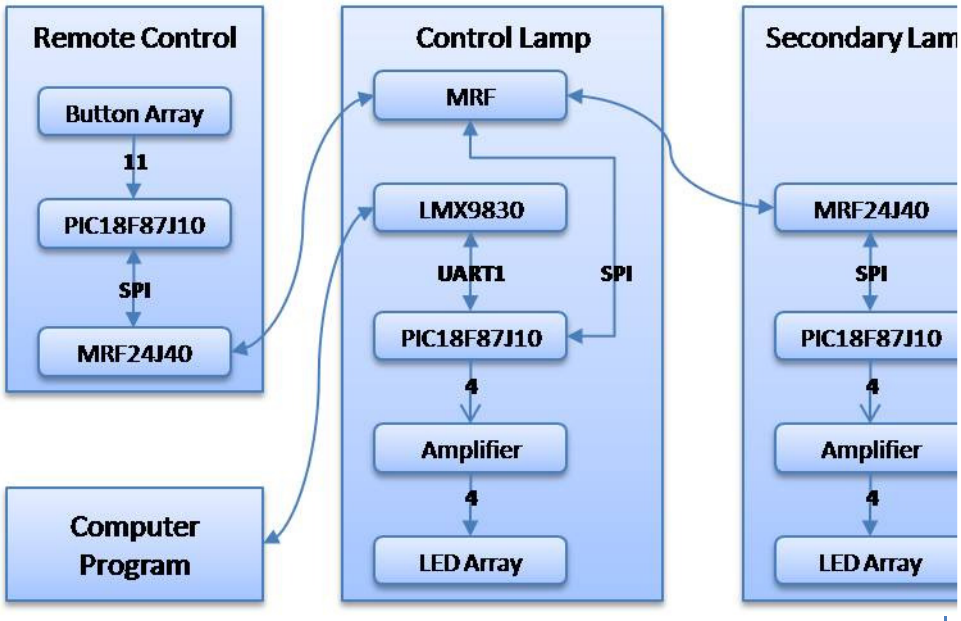

Figure 2 – Original Design Block Diagram

3.4.2 Remote Control

The remote control was designed to allow the users to communicate to any

light in the room from any position he/she is standing. The remote control is a nice feature to have with this lighting system because it does not limit the user to any distance from a light, but at the same time, it was designed for limited operability of the lights.

3.4.2.1 Power Supply

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3.4.2.4 Zigbee Chip

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3.4.2.5 Remote Control PCB Design

After all research was done on all of the different components that attached to processor and the Zigbee chip, a printed circuit board was created. Since the Zigbee is an RF transceiver, a lot of things had to be considered when laying out the board. The MRF24J40 Datasheet mentions everything that should be considered in the designing of a RF board. The datasheet also provided a suggested layout for the Zigbee chip, so the design that was approached was to follow Microchips design as closely as possible. The final layout is shown below in Figure 3.

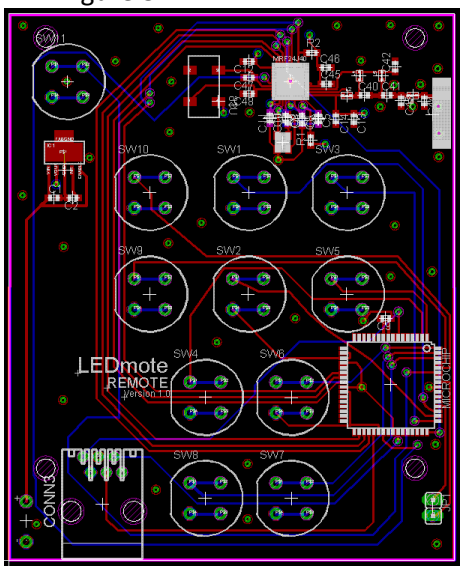

Figure 3 – Remote Control PCB Design

3.4.3 Control Lamp

3.4.3.1 Power Supply

The power supply for the lamp was designed a lot differently than in the remote control. The lamps were designed to be plugged into a 120V/60Hz or 240V/50Hz wall socket. So the first step was to send the voltage through a switch mode power supply, which would cut the voltage down to 12V DC. The

power supply that was chosen was a ETS120400UTC-P5P-SZ made by CUI Inc. From the datasheet it was found that this power supply could handle currents of up to 50A. This was a little over kill because currently the LED array draws a little less than 25A. It was chosen a little high in case more LEDs were needed in the future, which would ultimately draw more current. This power supply would then output 12V, as stated above, which would be used to drive the 12V LED array. But another step down in voltage was needed before it could be run to the microprocessors, which ran at 3.3V. To make this step down the same voltage regulator that was used in the remote control was again used.

3.4.3.2 Bluetooth Module

The Bluetooth module that was chosen was the LMX9830 Bluetooth Serial Port Module made by National Semiconductor. This Bluetooth module was chosen because it has its own processor embedded into it. With its own processor in it, the Bluetooth protocol stack does not have to be loaded onto the PIC18F87J10 like the Zigbee Stack does. Even though the price of this Bluetooth module was slightly higher because of the built in processor, it paid off because it would only be used in one lamp which would prevent the lighting system to be too expensive.

The Bluetooth module would connect to the microprocessor using a UART interface. The datasheet of the LMX9830 gives explicit directions on how the UART is set up. The UART in the LMX9830 supports a four wire connection, which operates better because it uses two recognition lines. But the LMX9830 can also connect to a two wire UART microprocessor, which the PIC18F87J10 only supports, this information can be found in the LMX9830 – Software Users Guide. It requires that the Clear To Send (CTS) input to be pulled ground. This will allow the two processors to properly talk to one another.

This Bluetooth module was used because it creates a Serial Port with another Bluetooth unit. Once it is connected as a Serial Port with another unit, the two Bluetooth units can transmit whatever data that is needed.

3.4.3.3 Amplifier Circuit

An amplifier circuit was needed because the PIC18F87J10 outputs 3.3V and the LEDs run on 12V. This would not allow the LEDs to light up properly because they would never get to the right voltage level. In order to drive the LEDs, a N-Channel MOSFET transistor was designed to step up the voltage. The transistors that were chosen were FDN339AN transistors made by Fairchild Semiconductor. The datasheet that went along with these transistors states that they can handle 20V and up to 3A. These transistors had to be rated high enough to handle the 2.3A draw from LEDs.

3.4.3.4 LED Array

The LED Array PCB can be seen in Figure 4. Using a set of four high power MOSFET transistors the current driven through each pair of LED's can be controlled. By pulse width modulating the base of each transistor the intensity of each color can be adjusted. The prototype array contains 8 RGB LEDs used to demonstrate color changes and ten white LEDs. The white LEDs are not mounted to the board in Figure 4 due to heat dissipation requirements. In

order to quickly dissipate heat, the white LEDs must be mounted to a specialized heat sink surface. If mounted to the PCB, the base of the PCB will likely melt. The white LEDs were mounted directly to the display lamp metal casing to allow heat dissipation. The white LEDs are connected to the pads shown at the top of the board. Current passes through four current-controlling resistors before passing through the LEDs. The white LEDs are paired in series so each of the first five pads shown (from left to right across the top of Figure 4) are connected in series to two white LEDs. Given the variability of the resistors and LEDs a worst case analysis was performed on this circuit to find the optimal values and tolerances for the resistors. This analysis can be seen in Appendix 10.3.

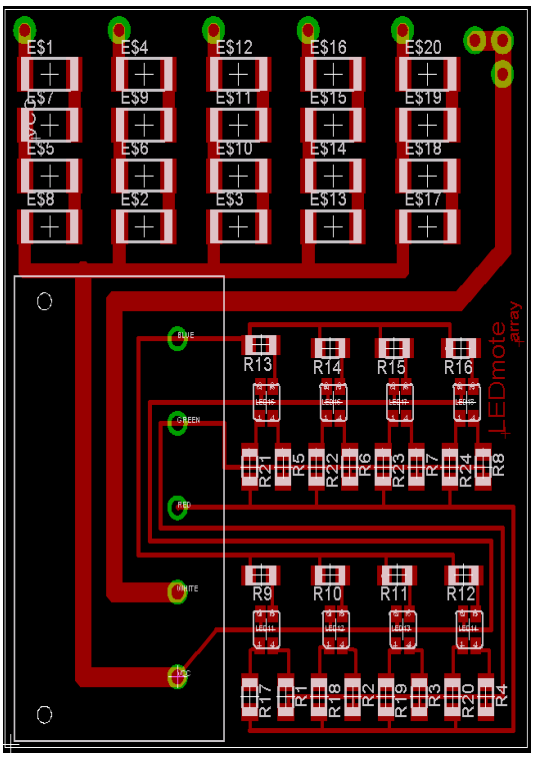

Figure 4 - LED Array

3.4.3.5 Lamp Base PCB

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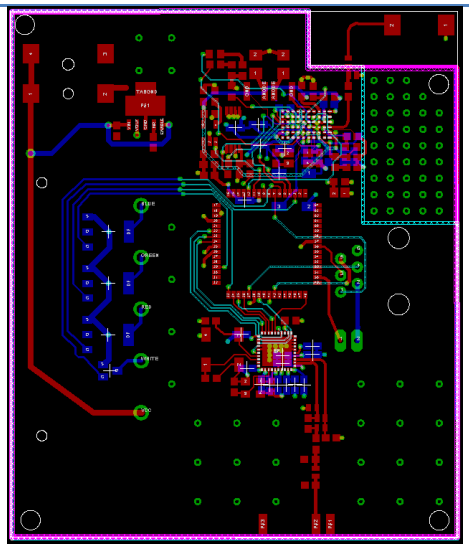

Figure 5 - Lamp Base

3.4.4 Secondary Lamps

The secondary lamps do not need any more explaining because they are basically just a striped down Control Lamp. The secondary lamps do not need a Bluetooth unit because these lamps just rely on the Zigbee modules to communicate to the rest of the lamp network.

Complications

PCB of Remote Device

Non-working PCB of Remote Device

3.5 No Connection to main MCU, Also see Section 4.3 Original Design

3.5.1 Overview

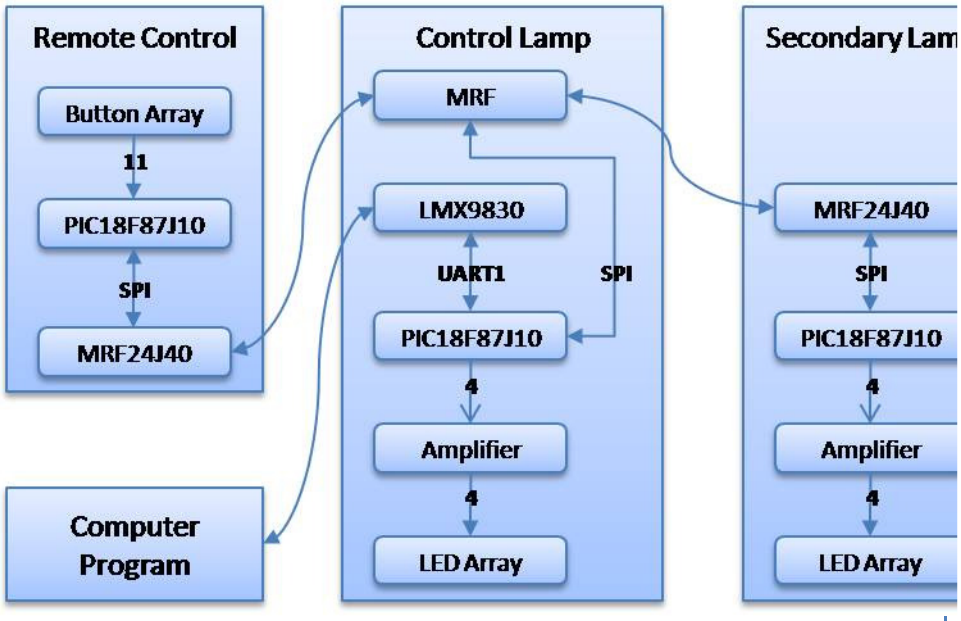

Figure 2 – Original Design Block Diagram

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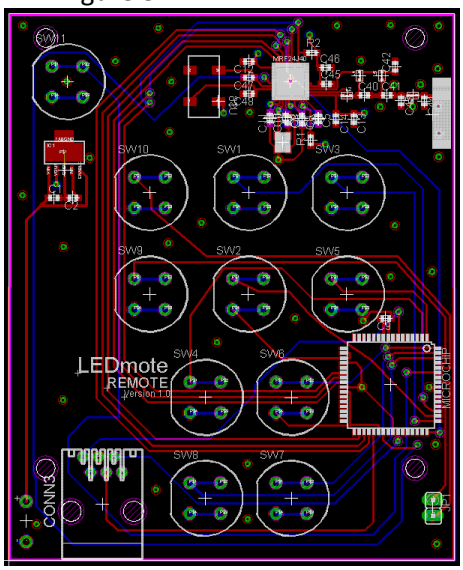

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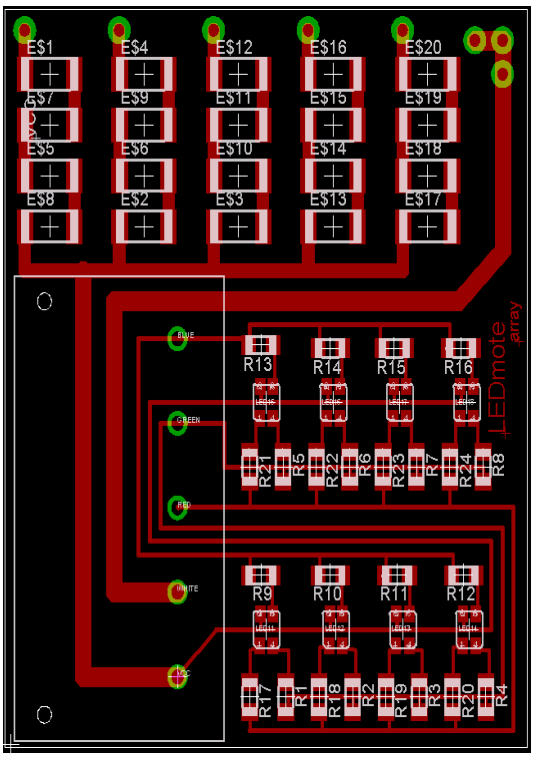

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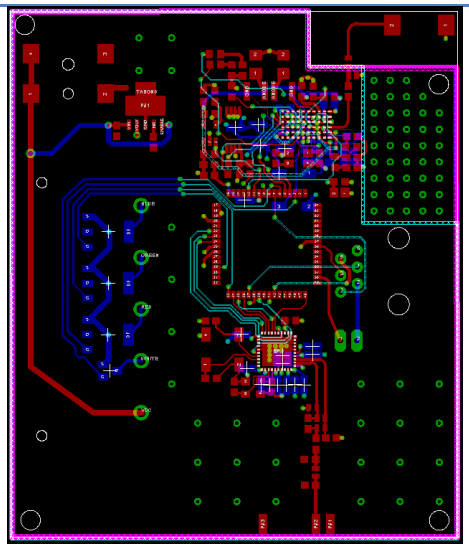

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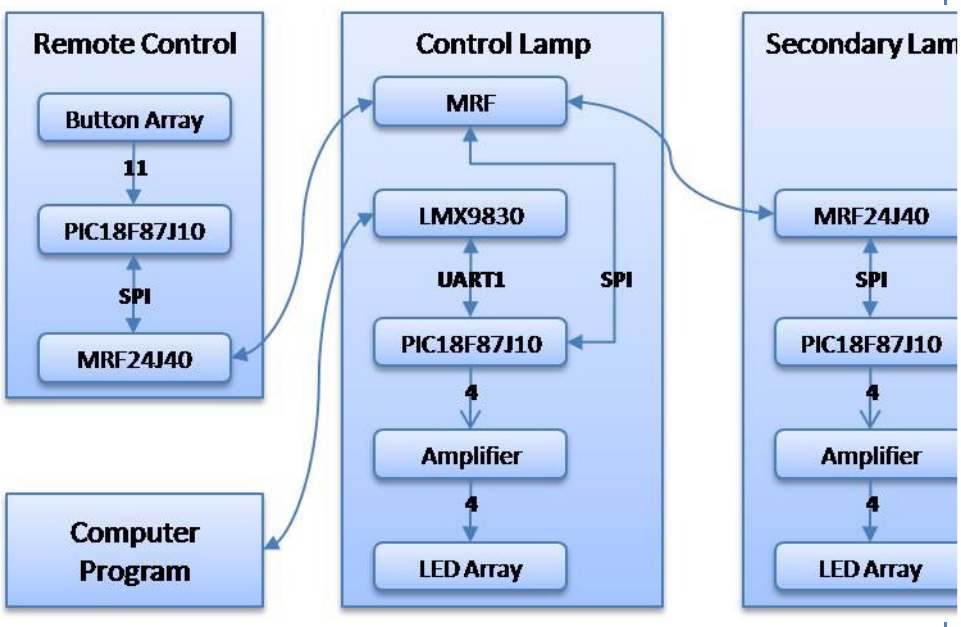
Complications

PCB of Lamp Base

Non-working PCB of Lamp Base

3.6 Short on the Board, Also see Section 4.3 Original Design

3.6.1 Overview



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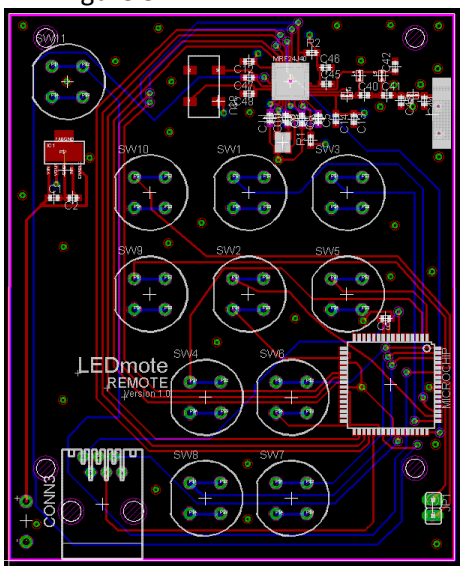

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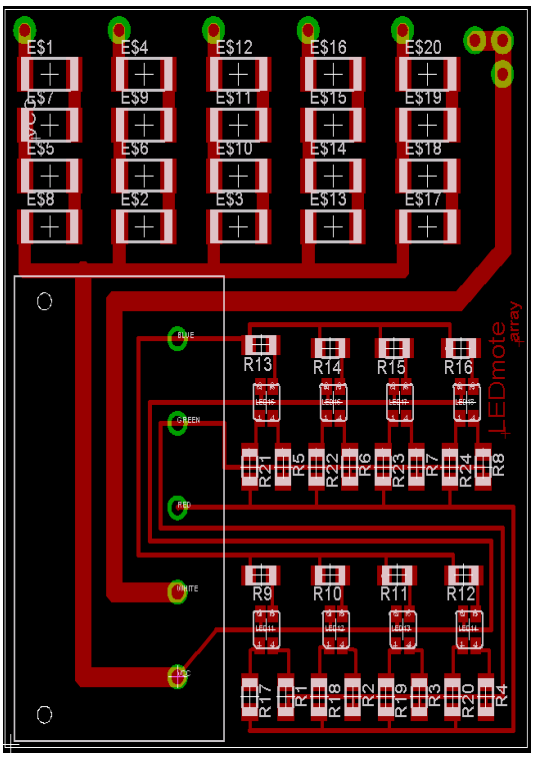

Figure 4 - LED Array

3.6.3.5 Lamp Base PCB

The lamp base printed circuit board was designed much in the same way as the remote control circuit board. With the development kit that was purchase for the LMX9830, some of the software that came with the kit provided the prints for the four layers of the development kit. These prints were replicated as close as possible just like the PIC18F87J10 and the MRF24J40 were before. Also, a bit of concern was created by the use of two RF modules on one board. The solution that was proposed by the team was to put the two RF modules as far away as possible. From Figure 5, it can be seen that the Bluetooth was populated near the top left and the MRF24J40 located at the bottom middle of the board.

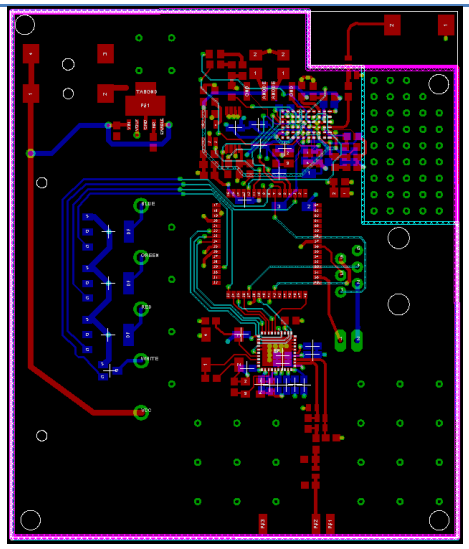

Figure 5 - Lamp Base

3.6.4 Secondary Lamps

The secondary lamps do not need any more explaining because they are basically just a striped down Control Lamp. The secondary lamps do not need a Bluetooth unit because these lamps just rely on the Zigbee modules to communicate to the rest of the lamp network.

		Complications
PC Software	PC Software	-

3.6.5 Electrical Requirements

In the Project Proposal and Feasibility Study that the team put together in the fall of 2006, there was a list of project requirements that would determine the degree of success of the project at the end of spring 2007. These requirements are listed in Table 3 below.

Table 3 - Electrical Characteristics Requirements Check

Description	Original Requirement	Final Prototype Attribute	Reason for Change
Number of total LEDs per lamp	10	18	More Light Output
White LEDs per lamp	4	10	More Light Output
RGB LEDs per lamp	6	8	More Light Output
Max intensity (white LEDs)	800 lumens	500 lumens[1]	Requires Less Light
Max intensity (RGB LEDs)	TBD	180 lumens[2]	Changed to Accent Lighting
Max current per white LED	400mA	500mA[3]	Increased Tolerances

[1] (Osram) Golden Dragon Datasheet
[2] (Osram) Tri-color LED Datasheet
[3] (Osram) Golden Dragon Datasheet

Description	Original Requirement	Final Prototype Attribute	Reason for Change
Max current per RGB LED	50mA	70mA[4]	Increased Tolerances
Lamp total power consumption	~25W	23W	Lower Power Consumption
Estimated number of colors	256	256	-
Dimming variability	Continuous	16 Segments	Simplifies Design while still maintaining appearance
Continuous operating Voltage	90VAC – 250VAC	100VAC – 240VAC[5]	Tighter Specs on Parts
Temperature	-10degC – 65degC	-10degC – 70degC[6]	Tighter Specs on Parts
Frequency	40Hz – 70Hz	47Hz – 63Hz[7]	Tighter Specs on Parts
Common voltage	5 VDC +/-5%	12VDC[8]	More Light Output
Common current	5A max	1.58A	Lower Power Consumption
White voltage	25V max	12V[9]	Fit to New Design
White current per LED	400mA max	157mA[10]	Lower Power Consumption
RGB voltage	25V max	12V	Fit to New Design
RGB current	500mA max continuous	57.5mA[11]	Lower Power Consumption
Operating System	Windows XP	Windows XP	-
PC Wireless Protocol	Bluetooth	Bluetooth	-
PC Operating distance	10 meters (30 feet)	10 meters (30 feet)	-
Remote Operating distance	10 meters (30 feet)	10 meters (30 feet)	-
Remote Wireless Protocol	Zigbee	Zigbee	-
Remote Functions	On/Off, Color, Intensity	On/Off, Color, Intensity	-

Some of the major changes to electrical characteristics occurred in the power consumption. Most notable was the change in the number of LEDs to use, which went from 4 white and 6 tri-colors to 10 white and 8 tri-color LEDs. However, the power consumption went from an estimated 25W to 23W, which ties directly into our design goal of making an efficient and low power lamp.

[4] (Osram) Tri-color LED Datasheet
[5] (CUI Inc.) Power Supply Datasheet
[6] (CUI Inc.) Power Supply Datasheet
[7] (CUI Inc.) Power Supply Datasheet
[8] (CUI Inc.) Power Supply Datasheet
[9] (CUI Inc.) Power Supply Datasheet
[10] (Osram) Golden Dragon Datasheet
[11] (Osram) Tri-color LED Datasheet

3.7 Production Design Requirements

The prototype built by Team LEDmote is designed to lead into a production phase implemented by Innotec.

3.7.1 PC Requirements

Please refer to the LEDmote PC Control Console User Manual to determine production requirements for the PC.

3.7.2 Electrical Requirements

Some flexibility was allowed in the production design electrical requirements to adjust the intensity of the LEDs. However it was assumed that once a base current had been chosen, little deviation would occur from this set current so that all intensity adjustments were implemented through the PWM instructions of the MCU. As can be seen in Table 3, the prototype common current was set at 1.58A, although this can be adjusted up to a maximum of 5A depending on the product's unique requirements[12]. The voltage across the LEDs should not exceed 25V.

3.7.3 LED Enclosure Requirements

While building the prototype, Team LEDmote did not study in depth the casing and reflective elements of a production system. There are many varieties of lamp fixtures that could potentially be designed to house the LEDs of each lamp module. In the case of room lighting, such fixtures should be used to distribute and diffuse the light evenly throughout a room. In both the room lighting case and the direct lighting case (for example – in the use of the system in a desk lamp) direct exposure of the eyes to the LEDs should be avoided.

From informal tests run on the prototype lamp, the team determined that a user should not to look directly at white LEDs running with a current greater than 500mA[13]. At this current, repeated exposure to the intensity of the light could cause some health risks and in the short term will likely cause some discomfort to the user. The team did not determine a maximum current for the RGB LEDs as all tested currents did not approach an intensity that caused any measure of discomfort.

3.7.4 Lamp Spacing Requirements

Test runs on the prototype indicated that the lamp's light, even when reflected, was clearly visible from distances of over 300ft. In production design of room lamps, the team recommends that the LEDs be directed downward in multiple directions through a transparent diffuser. The team recommends that lamps be spaced no more than 30ft apart to provide adequate lighting to the room. However, the lamps may be spaced at distances of up to 250ft (direct line of sight) if necessary. Spacing of lamps is limited only by the range of travel of Zigbee electromagnetic waves and the interference they encounter. Refer to Section 7.1.3 for documentation on testing of Zigbee communication in various environments. The current system can implement up to 180 separate Zigbee-equipped modules[14].

[12] (OSRAM)
[13] (OSRAM)
[14] (Microchip Technology Inc.)

The system requires that each lamp module be connected to a supply source. It is assumed that most production systems will use a mains voltage supply from a building's electrical system. However, the system should function normally if an alternative supply such as a generator or battery were to be used provided that such alternative supplies met the remaining electrical requirements. Each lamp must be provided with a 12VDC minimum common voltage to ensure proper operation. In the original design and in production this is provided by connecting a mains supply through a switch-mode power supply mounted directly to the lamp PCB. In the secondary design (and the prototype) the DC voltage was provided by Agilent E3620A and Hewlett Packard E3611A power supplies.

4 The Design

4.1 Design Overview

The design strategy used in the past semester was focused on getting a working prototype for Innotec to build upon when the project is continued by their engineers.

4.2 Design Decisions

4.2.1 Lamp Module Decision

The decision matrix, shown in Table 5.8, discusses the different alternatives on how the remote controls multiple lamps. The team decided that the remote would regulate all the lamp modules at the same time. Allowing the remote control to individually manipulate different lamps in the area was too complicated to fit into a single remote while still providing an ease of use to the consumer. The alternative was to create a lighting schedule with the remote control. This alternative did not stand up to other alternatives, adding unnecessary complexity to the remote control, and so increasing its cost.

Table 4.1 - Lamp Module Alternatives Decision Matrix

	Low Cost	Size	User Friendliness	Low Power	Reliability	Flexibility	Totals
Weights (out of 10)							
	10	7	3	7	8	5	
Lamp Module Alternatives							
Individual Lamp Modules	4	2	5	4	6	8	**185**

All Lamp Modules at Once	9	7	7	8	7	3	**287**
Scheduler Control	2	5	5	3	5	7	**166**

4.2.2 Lighting Decisions

While the actual market-product LEDs will be provided by Innotec, the team felt it was necessary for the remote control decision matrix (and subsequent control decisions) to examine the alternatives for LED lighting given the project requirements. The decision matrix, shown in Table 5.7, weighs the different lighting techniques of the Red Green Blue (RGB) LEDs and white LEDs. More specifically, it raises the question of how many different colors the remote control will offer and what range of dimming capabilities it can provide. Both of these options deal with how the remote control will increase the color or brightness level. This issue was not a problem for the remote because it has three different color buttons, each controlling one of the three colors in the RGB LED. It then sends out an up or down signal of the specific color pressed. The two different alternatives were weighted closely in the end because no significant additional design was needed to add more colors. The processor received a signal through the wireless transmitting device to increase the color by a certain increment for each button pressed.

Table 4.2 - Lighting Alternatives Decision Matrix

	Low Cost	Size	User Friendliness	Low Power	Reliability	Flexibility	Totals
Weights (out of 10)							
	10	7	3	7	8	5	
Lighting Alternatives							
Limited Color Option	8	7	4	8	7	3	**268**
256 Color Option	6	7	7	7	6	10	**277**
Limited Dimming Option	8	7	4	6	7	2	**249**
Continuous Dimming	7	5	7	6	5	9	**253**

4.2.3 Button Decision

This decision matrix, shown in Table 5.6, deals with the physical buttons of the remote control. For this project, three possible input devices were chosen: slides, individual buttons, and a scroll wheel. These

three options are shown below in Table 5.6, and weighted according to the criteria discussed above. The button alternative ended up slightly higher than the other two options because of its reliability. A slider has a preset position, which is a disadvantage if, when the lighting system is initially turned on, the lights automatically turn on to whatever preset position the slider is in. A user may not want the lights to be fully bright or fully dark when the lighting system is first turned on. The advantage of the other button systems is that, when the lighting system is turned on, it sets to a default medium brightness that can be adjusted up or down. There are no physical limitations on the button or scroll wheel system over the slider system. The main advantage of a button system over a scroll wheel system is minimization of costs.

Table 4.3 - Button Alternatives Decision Matrix

	Low Cost	Size	User Friendliness	Low Power	Reliability	Flexibility	Totals
Weights (out of 10)							
	10	7	3	7	8	5	
Button Alternatives							
Slides	7	7	7	6	5	6	**252**
Individual Buttons	6	5	7	7	8	8	**269**
Scroll Wheel (like iPOD)	3	6	7	7	7	9	**243**

4.2.4 Amplifier Decision

In researching the amplifier alternatives[15] and in discussions with Mr. Veenstra, the team determined that an ideal solution could be reached by using a combination of the first and third alternatives, i.e. using a high power transistor to output the necessary current together with PWM to vary the brightness.

[15] All About Circuits, *PWM power controller*. 2003 <http://www.allaboutcircuits.com/vol_6/chpt_6/9.html>

Table 4.4 - Amplifier Decision Matrix

	Low Cost	Flexibility of overall design	Size and Complexity	Availability	Reliability	Totals
Weights (out of 10)						
	8	9	7	5	10	
Switch Alternatives						
High-power transistor	6	8	7	8	8	**289**
Operational Amplifier/DCP	4	8	5	8	3	**209**
Pulse Modulation	9	8	9	10	10	**357**

4.2.5 Power Decision

Similarly to the decision matrix for the control system, the power system decision matrix showed very little difference between the two options. A centralized system is probably more cost-effective than a distributed system because it minimizes the number of power supplies. The team chose to use distributed power supplies on each of the lamp modules, since a centralized power supply would require the technicians who installed the lighting system to do additional wiring beyond that which the room already contains.

By using a system that has both distributed power and distributed control, the overall lighting system has maximum flexibility. Lamp modules could be designed not just as individual lighting units in rooms but could be used almost anywhere in a room (for example, as a desk lamp).

Table 4.5 - Power Decision Matrix

	low cost	flexibility of overall design	size	reliability		Totals
Weights (out of 10)						
	10	10	9	9		
Switch Alternatives						

Distributed	5	8	6	7		**247**
Centralized	7	4	8	7		**245**

4.2.6 System Decision

The decision matrix analysis shows that the pros and cons of each system were nearly balanced. The distributed control alternative provides the greatest amount of flexibility but the cost of installing a control in every fixture was cost inefficient. The centralized control option had the advantage of minimizing the necessary number of system processors and therefore reducing cost. However, centralized control reduces the flexibility of the project by forcing physical wiring to be installed between the control circuitry and the lamp modules. This seemed somewhat counter-intuitive to the team's objective of creating a wireless lighting system. Hence, despite distributed control only marginally beating out centralized control, the team chose a distributed control system for their design.

Table 4.6 - Control Decision Matrix

	low cost	flexibility of overall design	size	reliability		Totals
Weights (out of 10)						
	7	10	9	9		
Switch Alternatives						
Distributed	5	8	6	7		**232**
Centralized	7	4	8	7		**224**

4.2.7 Switch Decision

Wall-mounted switches controlled the power feed to all lamp modules. This provided a basic functionality in the event of failure or absence of wireless devices such as the remote control, laptop or in-room computer. The manual switching functionality was deemed essential for emergency cases. However, other functions of the lamp modules such as variable brightness and color were not built into the wall switches. Adding these features to a wall-mounted switch decreased the need for a wireless controller such as a remote or laptop. Thus the associated flexibility was reduced. The software and remote provided an on-off function for the lamp modules without the use of wall-mounted switches.

Table 4.7 - Wall Switch Decision Matrix

	low cost	flexibility of overall design	user friendliness	availability	reliability	Totals
Weights (out of 10)						
	9	9	10	7	10	
Switch Alternatives						
Simple on/off switch	9	9	8	8	10	**398**
Switch with all features	6	4	7	6	9	**292**

4.3 Original Design

4.3.1 Overview

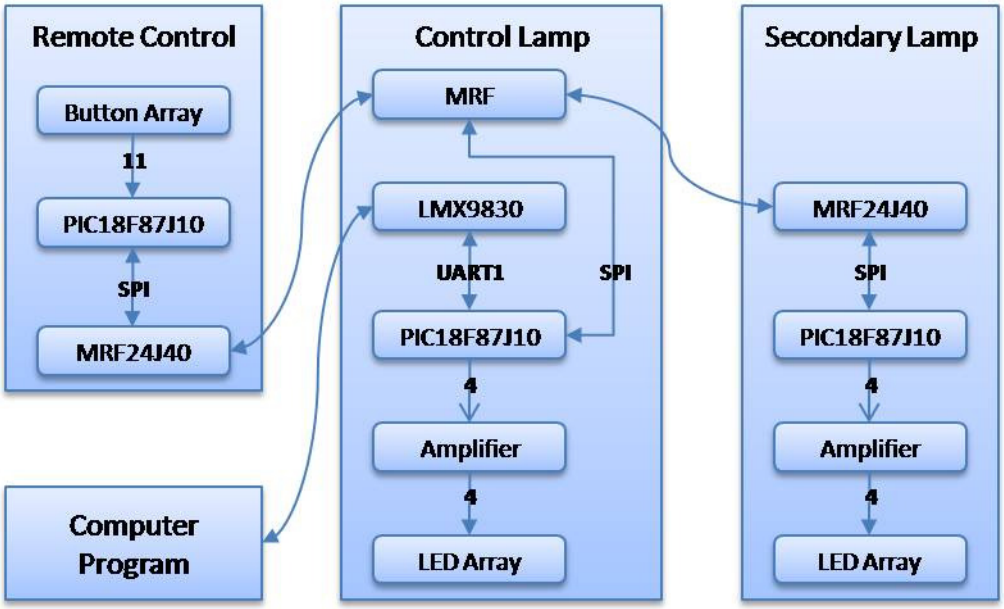

Figure 2 – Original Design Block Diagram

4.3.2 Remote Control

The remote control was designed to allow the users to communicate to any light in the room from any position he/she is standing. The remote control is a nice feature to have with this lighting system because it does not limit the user to any distance from a light, but at the same time, it was designed for limited operability of the lights.

4.3.2.1 Power Supply

The remote control was designed to use 2 AA batteries, which would produce a 4.5 V output onto the board. This was a little high because the processor and Zigbee module were specified to run at 3.3 V. To knock down the voltage to a tolerable level for the processor to handle, a REG103GA-3.3 linear voltage regulator was used. The datasheet[16] for this regulator, states that this voltage regulator can take an input of up to 15 V. This was nice to know because it can handle the input from the batteries. On an added note, the voltage regulator can also handle an input of 12 V, which the Lamp Modules run off of. This voltage regulator is also rated at 500 mA, this is well above the current that the main processor and the Zigbee processor ever pull.

4.3.2.2 Button Array

In creating a button array for the prototype, the team aimed to create an intuitive user interface. A power button served as an on/off switch for the display lamp. Other buttons consisted of three sets of two buttons to increase or decrease the amount of red, green and blue coloration added to the emitted light from the lamps. Finally, the remote control had increment and decrement buttons for the RGB LEDs and for all the white LEDs simultaneously.

The buttons that were chosen were from ITT Industries, and had the characteristics of normally open single pole single through buttons, which can be found on the SPST Momentary Key Switches Datasheet[17]. This allows us to connect the 3.3V line to one side of the push button and the other side to the processor, and when pushed the button would allow 3.3V to trigger the processor.

4.3.2.3 Processor

The processor that was chosen was the PIC18F87J10 made by microchip. This processor was chosen above other ones mainly because of its five pulse width modulation outputs, its two UART port modules and it ran on a common 3.3V input. As the search began for the processor, it was hard to find one with that many pwm outputs and two UART ports. When the project first began, the team was under the impression that two UARTs would be needed to connect to the Bluetooth module and the Zigbee module. This however changed along the way because it was found out that the Zigbee uses a Serial Port instead of a UART. The PIC18F87J10 was a very good processor for this project, and it was decided that it could be used in the remote control and the Lamps. The button inputs were designed to directly input into 11 different I/O Ports on the processor.

4.3.2.4 Zigbee Chip

Originally, the Freescale Semiconductor MC13192 was used. This Zigbee chip seemed to be the best chip that we could use at the time that we researched it. It was found to be able to connect to a large variety of microcontrollers through a SPI connection, which the PIC18F87J10 supports. So at the time it was assumed that the Zigbee protocol stack could have been loaded onto the PIC18F87J10. Although it was assumed that the MC13192 would be able to work with the PIC18F87J10, it was hard to find support for doing this.

[16] (Texas Instruments Incorporated)
[17] (ITT Industries)

Then around January, another chip made by Microchip was released. The Zigbee Chip that was selected was the MRF24J40. There was a lot more support for this chip and Microchip has its own Zigbee Protocol Stack specifically designed for PIC18F Microcontrollers. The support for loading the stack onto a PIC18F processor can be found in the AN965: Microchip Stack for the ZigBee™ Protocol Datasheet[18]. This chip was selected because microchip fully supports this Zigbee chip with the PIC18F87J10. This Zigbee chip was designed to connect through the SPI port on the PIC18F87J10 and was also designed to send out a clock output for the PIC18F87J10 to use.

4.3.2.5 Remote Control PCB Design

After all research was done on all of the different components that attached to processor and the Zigbee chip, a printed circuit board was created. Since the Zigbee is an RF transceiver, a lot of things had to be considered when laying out the board. The MRF24J40 Datasheet[19] mentions everything that should be considered in the designing of a RF board. The datasheet also provided a suggested layout for the Zigbee chip, so the design that was approached was to follow Microchips design as closely as possible. The final layout is shown below in Figure 3.

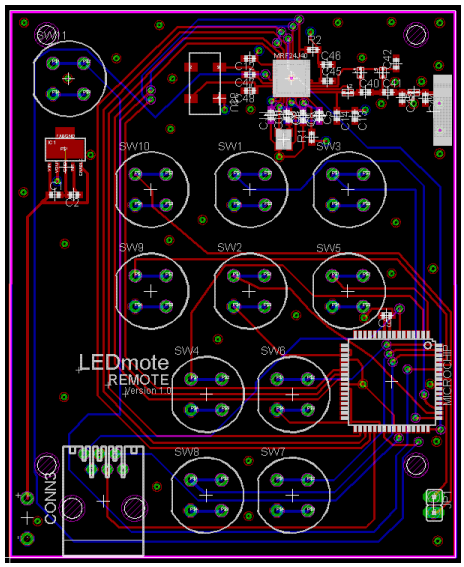

Figure 3 – Remote Control PCB Design

4.3.3 Control Lamp

4.3.3.1 Power Supply

The power supply for the lamp was designed a lot differently than in the remote control. The lamps were designed to be plugged into a 120V/60Hz or 240V/50Hz wall socket. So the first step was to send the voltage through a switch mode power supply, which would cut the voltage down to 12V DC. The power supply that was chosen was a ETS120400UTC-P5P-SZ made by CUI Inc. From the datasheet[20] it was found that this power supply could handle currents of up to 50A. This was a little over kill because

[18] (Microchip Technology Inc.)
[19] (Microchip Technologies Inc.)
[20] (CUI Inc.)

currently the LED array draws a little less than 25A. It was chosen a little high in case more LEDs were needed in the future, which would ultimately draw more current. This power supply would then output 12V, as stated above, which would be used to drive the 12V LED array. But another step down in voltage was needed before it could be run to the microprocessors, which ran at 3.3V. To make this step down the same voltage regulator that was used in the remote control was again used.

4.3.3.2 Bluetooth Module

The Bluetooth module that was chosen was the LMX9830 Bluetooth Serial Port Module made by National Semiconductor. This Bluetooth module was chosen because it has its own processor embedded into it. With its own processor in it, the Bluetooth protocol stack does not have to be loaded onto the PIC18F87J10 like the Zigbee Stack does. Even though the price of this Bluetooth module was slightly higher because of the built in processor, it paid off because it would only be used in one lamp which would prevent the lighting system to be too expensive.

The Bluetooth module would connect to the microprocessor using a UART interface. The datasheet[21] of the LMX9830 gives explicit directions on how the UART is set up. The UART in the LMX9830 supports a four wire connection, which operates better because it uses two recognition lines. But the LMX9830 can also connect to a two wire UART microprocessor, which the PIC18F87J10 only supports, this information can be found in the LMX9830 – Software Users Guide[22]. It requires that the Clear To Send (CTS) input to be pulled ground. This will allow the two processors to properly talk to one another.

This Bluetooth module was used because it creates a Serial Port with another Bluetooth unit. Once it is connected as a Serial Port with another unit, the two Bluetooth units can transmit whatever data that is needed.

4.3.3.3 Amplifier Circuit

An amplifier circuit was needed because the PIC18F87J10 outputs 3.3V and the LEDs run on 12V. This would not allow the LEDs to light up properly because they would never get to the right voltage level. In order to drive the LEDs, a N-Channel MOSFET transistor was designed to step up the voltage. The transistors that were chosen were FDN339AN transistors made by Fairchild Semiconductor. The datasheet[23] that went along with these transistors states that they can handle 20V and up to 3A. These transistors had to be rated high enough to handle the 2.3A draw from LEDs.

4.3.3.4 LED Array

The LED Array PCB can be seen in Figure 4. Using a set of four high power MOSFET transistors the current driven through each pair of LED's can be controlled. By pulse width modulating the base of each transistor the intensity of each color can be adjusted. The prototype array contains 8 RGB LEDs used to demonstrate color changes and ten white LEDs. The white LEDs are not mounted to the board in Figure 4 due to heat dissipation requirements. In order to quickly dissipate heat, the white LEDs must be mounted to a specialized heat sink surface. If mounted to the PCB, the base of the PCB will likely melt.

[21] (National Semiconductor Co.)
[22] (National Semiconductor Co.)
[23] (Fairchild Semiconductor)

The white LEDs were mounted directly to the display lamp metal casing to allow heat dissipation. The white LEDs are connected to the pads shown at the top of the board. Current passes through four current-controlling resistors before passing through the LEDs. The white LEDs are paired in series so each of the first five pads shown (from left to right across the top of Figure 4) are connected in series to two white LEDs. Given the variability of the resistors and LEDs a worst case analysis was performed on this circuit to find the optimal values and tolerances for the resistors. This analysis can be seen in Appendix 10.3.

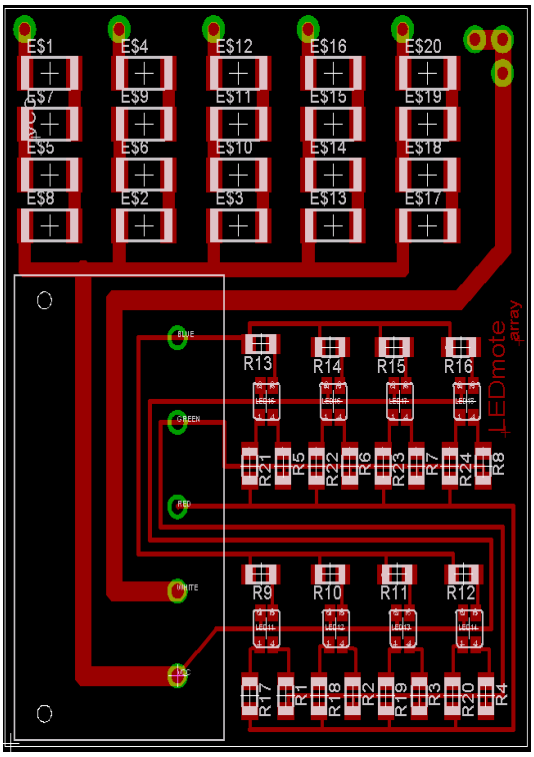

Figure 4 - LED Array

4.3.3.5 Lamp Base PCB

The lamp base printed circuit board was designed much in the same way as the remote control circuit board. With the development kit that was purchase for the LMX9830, some of the software that came with the kit provided the prints for the four layers of the development kit. These prints were replicated as close as possible just like the PIC18F87J10 and the MRF24J40 were before. Also, a bit of concern was created by the use of two RF modules on one board. The solution that was proposed by the team was to put the two RF modules as far away as possible. From Figure 5, it can be seen that the Bluetooth was populated near the top left and the MRF24J40 located at the bottom middle of the board.

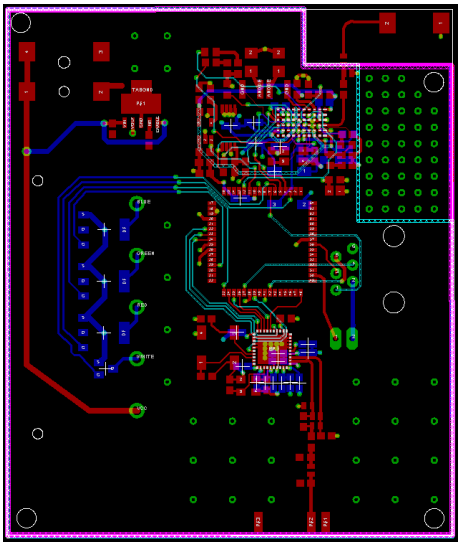

Figure 5 - Lamp Base

4.3.4 Secondary Lamps

The secondary lamps do not need any more explaining because they are basically just a striped down Control Lamp. The secondary lamps do not need a Bluetooth unit because these lamps just rely on the Zigbee modules to communicate to the rest of the lamp network.

4.4 Complications

The original plan had some significant complications caused both by the design and fabrication of the PCBs.

4.4.1 Remote Complications

In the Remote Control Circuit, the MCU received an oscillating external signal from the Zigbee transceiver clock. The Zigbee transceiver outputs a clock signal with a frequency of 2.5MHz, which is below the minimum input clock rate for the MCU of 10MHz.[24] Therefore; the MCU was unable to function properly and did not acknowledge itself when contacted by the ICD2 programmer.

"In EC mode the 2.5MHz crystal can be run, but only thing is that few of the peripherals may run very slow." [25]

This quote from Microchip support and data from the Microchip data sheet[26] lead the team to believe that correct connection to the chip was not attainable while receiving a 2.5MHz clock from the Zigbee module. The chip ran properly, as detected from the clock division output. This output provided a ¼ frequency output clock, which was successfully determined through views on an oscilloscope. All VCC inputs were receiving proper voltages and all GND inputs were grounded. However when addressed by the program, the chip did not respond with an identification code, as the chip on the development board did.

[24] (Microchip Technology Inc.)
[25] Support Response 4/6/2007 4:09 AM – Microchip Support
[26] (Microchip Technologies Inc.)

4.4.2 Lamp Base Complications

The Lamp Base also had the same issues that were designed into the remote board. Also, the lamp base had a short underneath the Bluetooth chip. This chip was a 60 pin Ball grid array (BGA) measuring 6mm by 9mm, leaving very little room for error. As the soldering paste melted beneath the chip, it was determined that a solder bridge was formed across pins that are connected to power and ground. This caused the board to not power up properly and tests showed that this weak power signal was insufficient to supply the microcontroller.

4.4.3 Complications Conclusion

Because of the previously mentioned complications, the original plan had to be put aside in favor of the secondary plan. The secondary plan was then implemented because it implemented the use of key hardware predesigned and prefabricated in the form of development kits.

4.5 Final Prototype

The final prototype had three modules to it the remote control, control lamp and a computer program. The prototype block diagram can be seen below in Figure 6. The red blocks represent the portions that were added to the design and the orange blocks represent the parts that were just modified or swapped out for different components. The following sections lay out the decisions, hardware and software of the final prototype.

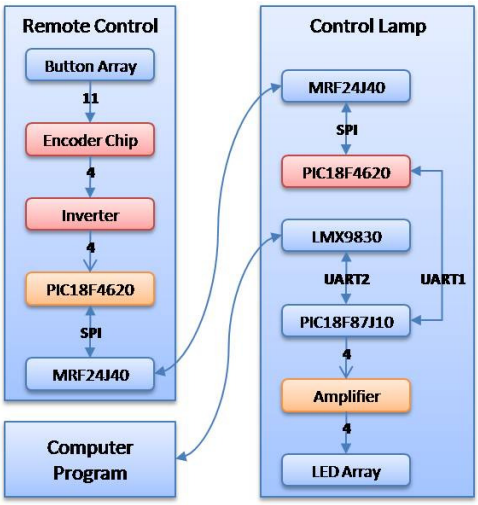

Figure 6 – Prototype Block Diagram

4.5.1 Hardware Solution

4.5.1.1 Development Kits

In implementing hardware, the team chose to use two different development kits provided by Microchip. The first was the HPC Explorer board, which included a PIC18F8722, convenient connectors for programming and I/O, LEDs, a 10MHz crystal and several buttons. The team used the HPC board as a central controller that could take Zigbee-communicated inputs from the remote control as well as

Bluetooth-communicated inputs from the PC while outputting a signal to light up the specified LEDs. The second development kit was the PICDEM Z, two of which were used in the secondary design. The PICDEM Z board is a recent design by Microchip, created specifically for testing communication through Zigbee. One of the boards was used as a basis for the remote control while the other was used to communicate with the HPC board via UART hardwired connections. The PICDEM Z has a PIC18LF4620 processor, a MRF24J40 transceiver daughter card and many similar features to the HPC board.

4.5.1.2 Remote Control

The prototype remote control was made up of bread-boarded components. A remote control PCB was designed and populated for demonstration. Unfortunately, it only had partial functionality, so the team decided it should not be used. The likely cause of malfunction was the difficulties in soldering the parts to the board, resulting in some components not making a clean electrical connection to the rest of the circuit.

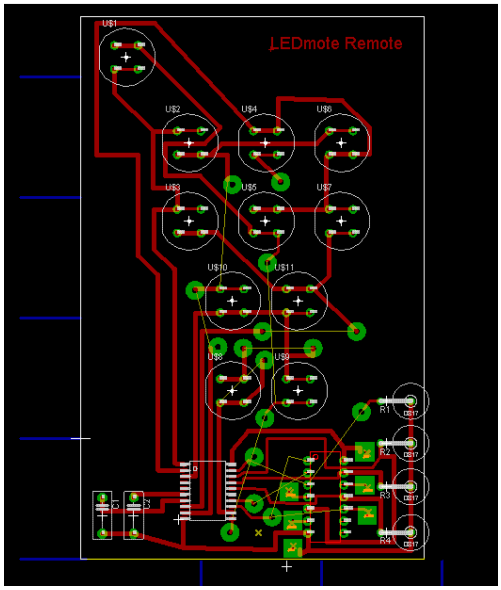

Figure 7 - Prototype Remote Control PCB Layout

4.5.1.2.1 Button Array

The power button was placed at the upper left corner of the remote (as it lay in the user's hand) – a standard position for an on/off switch in many remote controllers. The increment buttons for the red, green and blue colors were placed above the decrement buttons. The increment buttons for the all color and white were placed on the right side, while the decrement was placed on the left. The team felt that this was the most intuitive layout. This layout can be seen in Figure 7.

The team chose to use small, round buttons for the prototype to minimize space requirements on the remote control. Red, Green and Blue buttons were selected to correspond to the red, blue and green color increases. White buttons were designated to represent increases and decreases in white color. Black buttons were designated to represent increases and decreases in all three colors. A yellow button was selected as a power button.

4.5.1.2.2 Encoder

The team chose to use an MM74C922 encoder chip[27] after realizing that a compatibility issue had arisen. The remote control needed to have 11 input buttons to the PIC18F4620 processor, but the processor only had 4 inputs. The encoder's main function was to serve as a matrix so that the correct signals would be passed to the processor. The selected encoder also had an inbuilt debouncer, which circumvented the difficulties the team had previously experienced with bouncing. The encoder datasheet showed a simple design for asynchrous data entry onto a bus, providing a very similar circuit to our needs. This circuit included an oscillator function using a capacitor connected to ground and an inverter set up on the Data Available pin to set up the Output Enable pin so that the encoder signals could be read by the processor.

4.5.1.2.3 Inverter

The team found it necessary to include an inverter chip in the remote control design because the processor recognized a change to a low voltage from a default high voltage while the encoder output a higher voltage upon a button push input. The MM74C04N inverter chip[28] was chosen as it was readily available and appeared to function effectively. The team discovered that the inverter worked most effectively when the output from the encoder was tied to a pull-down resistor so that the current reaching the inverter was low. In the prototype, these pull-down resistors had a value of 10MΩ.

4.5.1.2.4 PIC18F4620

In the prototype of our design, the PIC18F4620[29] was used as part of the PICDEM Z[30] development kit. The original design called for the PIC18F87J10 processor, but the -4620 came pre-installed in the development kit and so the team chose to do some research on this processor and use it instead of the -87J10 in the remote control. The -4620 on the development kit came with the hardware necessary to take inputs and then output to the Zigbee daughter card[31].

4.5.1.3 Lamp Base

4.5.1.3.1 Amplifier

The amplifier circuit was designed to amplify the signal from the microprocessor to the LEDs. Since the processor only outputs a voltage of 3.3V and the LEDs required a higher voltage to operate correctly, selecting the correct amplifier circuitry proved important.

[27] (Fairchild Semiconductor)
[28] (Fairchild Semiconductor)
[29] (Microchip Technology Inc.)
[30] (Microchip Technology Inc.)
[31] (Microchip Technology Inc.)

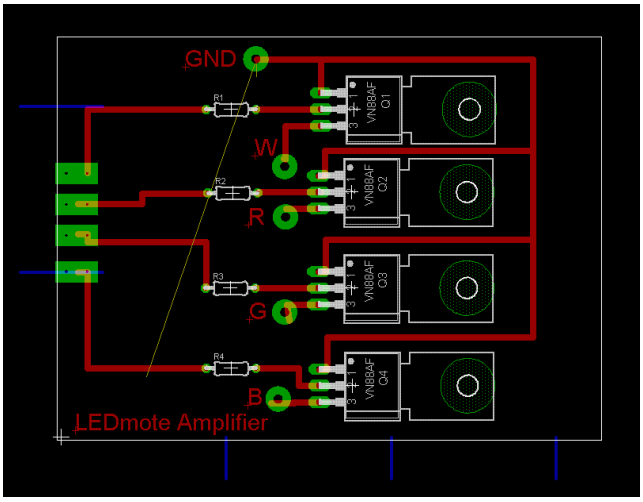

Figure 8 - Prototype Amplifier PCB

The amplifier circuit consisted of 4 inputs from the PIC18F87J10 processor, resistors, transistors and output pins. The transistors were used as the actual amplifiers that allow for adjustments in the LEDs. The resistance of the gate resistors was required to be greater than Rmin in order to limit the output current of the Microcontroller. The calculation of Rmin is seen in Figure 9.

$$V_{pwm} := 3.3V \qquad I_{max} := 15mA$$

$$R_{min} := \frac{V_{pwm}}{I_{max}} \qquad R_{min} = 220\ \Omega$$

Figure 9 - Rmin Calculation

With a MOSFET transistor, shown in Figure 11, the gate and source together was modeled as a capacitor. This created an RC circuit, which dampened the PWM if the RC time constant was low enough. To ensure that this did not occur, the RC time constant was set to be a factor of 10 less than the period of the PWM. The following equations calculated Rmax as a result of these considerations.

$$C_{gs} := 50pF \qquad T_{pwm} := 102\mu s$$

$$R_{max} := \frac{T_{pwm}}{10 \cdot C_{gs}} \qquad R_{max} = 204k\Omega$$

Figure 10 - Rmax Calculation

Considerations for the transistors in the design of the Amplifier Circuit were such that they must handle the drain-to-source voltage so that the transistors were not destroyed by overly high currents. The resistors are rated at 10kΩ - a value assigned because it was between Rmin and Rmax. Also, the

transistors must be activated by a 3.3V gate-to-source voltage, because this was what the chip driving the amplifier was able to produce.

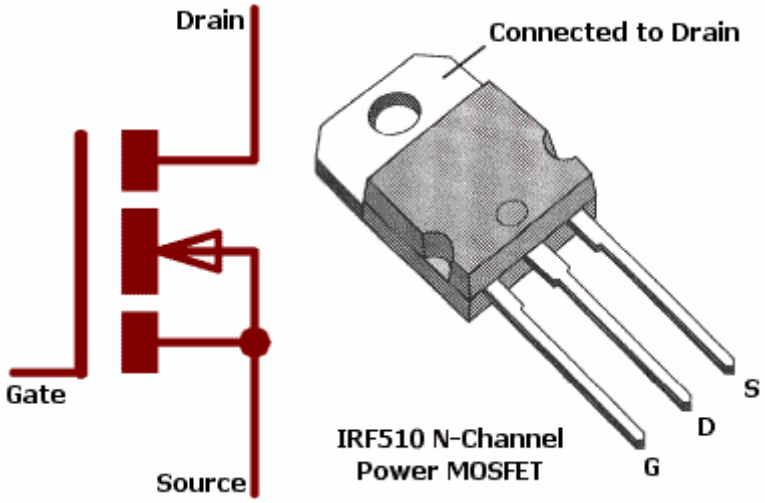

Figure 11 - MOSFET Transistor

4.5.1.3.2 Display Lamp

The display lamp came with a mounted switch as an example of the wall-mounted switch as described in Section 4.2.7. The LED Array PCB was mounted in an orientation such that white light reflected effectively off the white paper backing of the display lamp and also off of the diamond-plated steel used to shield observers from direct eye contact with the white LEDs. Additionally, two semicircular sheets of plastic were inserted in the steel plating to distinguish the color LED operation from the white LEDs. The display lamp (in operation) can be seen in Figure 12.

WALL LAMP
· Light Emitting Diode Technology
· 10 White LEDs
· 9 Multicolor RGB LEDs
· 22 Watts Max Power Consumption
· 2.4 GHz Bluetooth & ZigBee Modules
· 256 Accent Colors
INNOTEC

Figure 12 - Display Lamp

4.5.2 Software Solution

4.5.2.1 PC Software

As discussed in the Business Plan section, the operating system used for the design of the software was Windows XP. The prototype was designed on Windows XP SP2.

4.5.2.1.1 Programming Language

4.5.2.1.1.1 Criteria

Selecting an appropriate software programming language was vital to time expenses and functionality. If an unfamiliar language was selected, then more time must be spent in familiarization with the language. If a tedious language was selected, more time must be spent in programming the intricacies of the language. Therefore, one heavily weighted criterion was how familiar the team was with the language. This was measured as the amount of previous experience team members had with each language. It was considered whether or not the language was adequate to fulfill the desired functions of software for this project. The software needed to interface with a Bluetooth card. The capability to create a graphical user interface (GUI) that is transparent to the user was also required. It had to be capable of creating applications compatible with Windows; because that was the OS we intended to install our prototype software on. Without adequate software no matter how familiar the team was with the language, certain functions could not be created. Another criterion was an adequate support system to answer all programming queries. In summary, the criteria were previous experience, functional Bluetooth interface, capacity to create transparent GUI, ability to create windows compatible applications, and an adequate support system.

4.5.2.1.1.2 Alternatives

There were three alternatives considered for software programming language. The alternatives were Java, C++, and Basic. Java is an object-oriented programming language developed by Sun Microsystems. It was designed to be executed on multiple operating systems. It was also designed for using computer networks.[32] C++ is a high-level programming language originally developed by Bell Labs.[33] Basic stands for "Beginner's All-purpose Symbolic Instruction Code" and originated at Dartmouth College. It was created as a programming language for the non-technical user.[34]

4.5.2.1.1.3 Decision

The decision matrix in Table 4.8 shows Visual Basic as the superior programming language choice for software development. The major factor in making this decision was that the team had more collective experience in coding Visual Basic. This included having two year intern work experience with Visual Basic software. Other factors that supported this decision were the extensive support structure available on MSDN (Microsoft Developer Network). MSDN has extensive resources in developing software with specific applications for windows, developing GUI, and interfacing to Bluetooth.[35] Java has a wide variety of applications and all the required capabilities. However, the team's unfamiliarity with the language and its unknown complexities ruled Java out as an acceptable alternative. Although the team has had two classes on C++, the experience and ease of use of Visual Basic ruled out the use of C++.

Table 4.8 – Programming Language Decision Matrix

	Previous Experience	Interface to Bluetooth	GUI Development	Windows Development	Support System	**Totals**
Weights (out of 10)						
	7	10	8	6	7	
IDE						
Java	3	8	8	9	7	268
C++	3	10	8	9	10	309
Basic	9	10	9	5	9	328

[32] *Java (Programming Language).* Wikipedia, 7 December 2006. <http://en.wikipedia.org/wiki/Java_%28programming_language%29>
[33] *C++*. Wikipedia, 7 December 2006. <http://en.wikipedia.org/wiki/C%2B%2B>
[34] *BASIC*. Wikipedia, 7 December 2006. <http://en.wikipedia.org/wiki/BASIC>
[35] MSDN. 7 December 2006. <http://msdn2.microsoft.com/en-us/default.aspx >

4.5.2.1.2 Software Design

4.5.2.1.2.1 Software Architecture

The software architecture, shown in Figure 13, was the hierarchy leading from the user interface to the Bluetooth module.

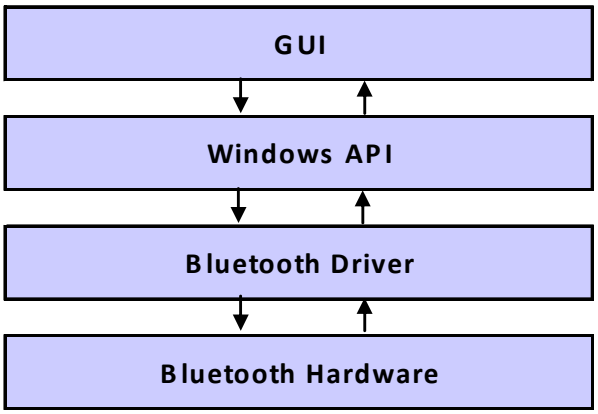

Figure 13 - Software Architecture

The GUI received input and displayed output directly to the user. When receiving an input from the user, the GUI transfered it through a Windows API to the Bluetooth Driver and directed the Bluetooth hardware to send the desired instruction. The instruction was decoded in the hardware by the controller and pulses were sent to LEDs. When a command was received by the controller from the remote, it relays onto other Zigbee devices and relayed back through Bluetooth transmission to the laptop controller. When received by the Bluetooth hardware on the laptop, the signal percolated back up the hierarchy and was reflected in the GUI by a change in either the color selected or white LED intensity setting.

4.5.2.1.2.2 GUI Layout

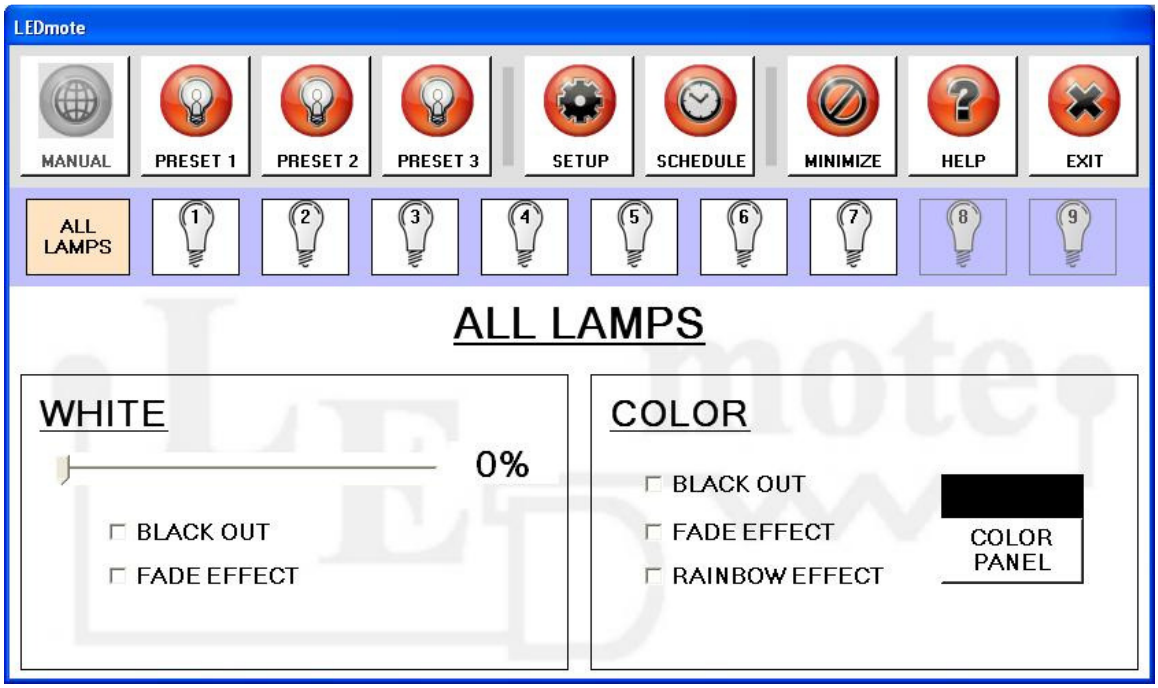

Figure 14 - GUI Layout

The concept of the GUI is illustrated in Figure 1Figure 14. All features of the GUI are subject to change. The GUI will vary greatly depending on the environment and size of the lighting system. The functions and user operation are explained in detail in the LEDmote PC Console Version 1.0 User Manual[36].

[36] (Veldkamp)

4.5.2.1.2.3 GUI Architecture

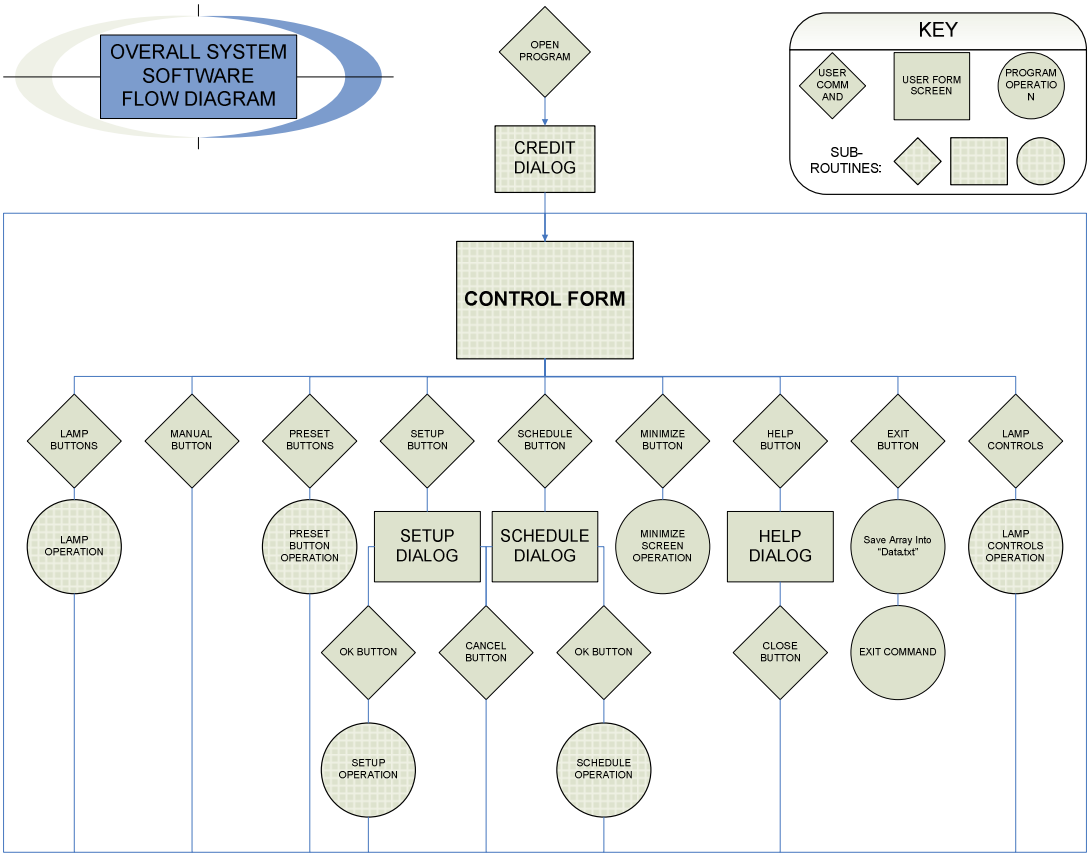

Figure 15 - Overall System Software Flow Diagram

The GUI software interface consisted of five user forms and layouts. When the user double clicks the executable file, the interface opens into the credit dialog screen. Throughout the duration of this screen, a number of actions are performed in the system. The breakdown of these actions is shown in Figure 15. The entire system can be broken down into process flow diagrams. All of the variables were stored in a large array. This array contained all the information for each individual lamp. The breakdown of the array components are listed below in Figure 16.

```
'------ System Array Settings ------
'CurrentArray(Lamp, Variable)
'  Variable:
'       0 - Lamp Name
'       1 - White Intensity
'       2 - Color Intensity
'       3 - Red
'       4 - Green
'       5 - Blue
'       6 - White Fade
'       7 - Color Fade
'       8 - White Blackout
'       9 - Color Blackout
'       10- Rainbow Effect
'-------------------------------------
```

Figure 16 - System Array Settings

Each function and control in Figure 15 was broken down into the sections below to explain their function and codes.

4.5.2.1.2.3.1 CREDIT DIALOG

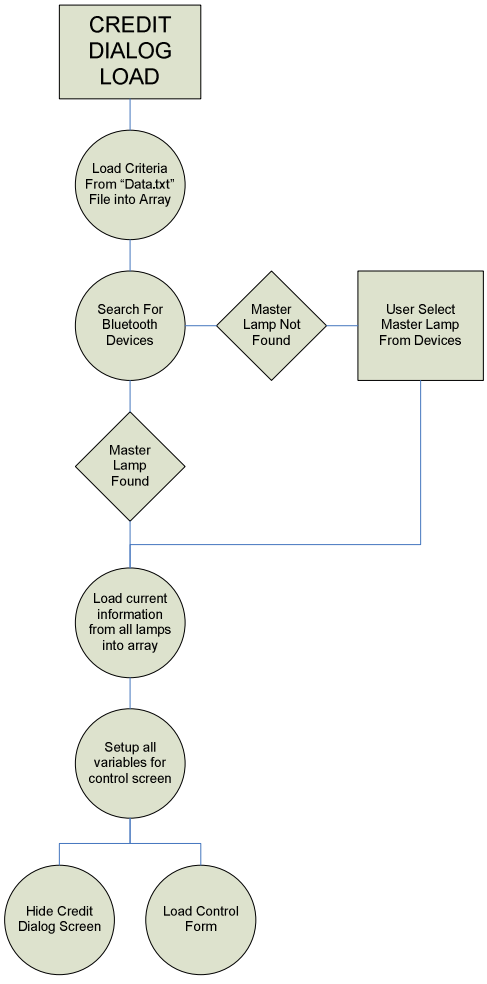
CREDIT DIALOG LOAD
Load Criteria From "Data.txt" File into Array
Search For Bluetooth Devices
Master Lamp Not Found
User Select Master Lamp From Devices
Master Lamp Found
Load current information from all lamps into array
Setup all variables for control screen
Hide Credit Dialog Screen
Load Control Form

Figure 17 - Credit Dialog Form Process Flow

During the credit dialog process flow the program began by loading the data.txt file into the system array. An excerpt from the data.txt file is pasted below:

#0#18#0#255#128#0#False#False#False#False#False#0#18#0#255#128#0#False#False#False#False#False#0#18#0#255#128#0#False#False# …

The system array was set up as the storage structure for the lamp settings and values. The "#" was used as the delimiter separating the variables. Once this file was loaded into the array, the credit dialog activates a search for local Bluetooth devices in the computers area. A list of Bluetooth devices was compiled and compared to the stored master lamp name. If no device was found that matches the master lamp name, or no master lamp has been previously designated a list of potential devices was displayed to the user. Once the master lamp was found and/or chosen the program retrieved information from all the lamps. The lamps current settings were downloaded into the array and variables such as the number of lamps were set. Finally the credit dialog screen was hidden and the control form was loaded.

4.5.2.1.2.3.2 CONTROL FORM

The control form took the variables and array set by the credit dialog and displayed these variables to the user via the interface shown in Figure 14. The entire code for this interface could be found in the electronic documents submitted with this report (LEDmoteControl.txt). The control form had a group of buttons that performed their specified events. These events and their actions are laid out in Figure 16.

4.5.2.1.2.3.3 LAMP BUTTONS

The PC Control Console V1.0 has ten lamp buttons (All Lamps, 1-9). When any of these buttons were pressed the following code was executed:

```
Private Sub BTN_all_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_all.Click
    NewLamp = "ALL LAMPS"
    Call Change_Lamp()
End Sub
```

The system contains two global variables, CurrentLamp and NewLamp. When a lamp button is pressed the NewLamp variable is changed to the desired lamp change. The Change_Lamp subroutine that is called is shown below:

```
Private Sub Change_Lamp()
     ' Sets the values in user-interface to values of the current array
    If NewLamp = "ALL LAMPS" Then
       lblCurrentLamp.Text = "ALL LAMPS"
       WhiteBar.Value = CurrentArray(0, 1)
       WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
       chkBlackOutWhite.Checked = CurrentArray(0, 8)
       chkBlackOutColor.Checked = CurrentArray(0, 9)
       chkFadeWhite.Checked = CurrentArray(0, 6)
       chkFadeColor.Checked = CurrentArray(0, 7)
       chkRainbow.Checked = CurrentArray(0, 10)
        PictureBox1.BackColor = System.Drawing.Color.FromArgb(CType(CType(CurrentArray(0, 3), Byte), Integer),
            CType(CType(CurrentArray(0, 4), Byte), Integer), CType(CType(CurrentArray(0, 5), Byte), Integer))
    Else
     ' Sets the values in user-interface to values of the new lamp in current array
```

```
    lblCurrentLamp.Text = "LAMP " & NewLamp + 1
    WhiteBar.Value = CurrentArray(NewLamp, 1)
    WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
    chkBlackOutWhite.Checked = CurrentArray(NewLamp, 8)
    chkBlackOutColor.Checked = CurrentArray(NewLamp, 9)
    chkFadeWhite.Checked = CurrentArray(NewLamp, 6)
    chkFadeColor.Checked = CurrentArray(NewLamp, 7)
    chkRainbow.Checked = CurrentArray(NewLamp, 10)
     PictureBox1.BackColor = System.Drawing.Color.FromArgb(CType(CType(CurrentArray(NewLamp, 3), Byte), Integer),
         CType(CType(CurrentArray(NewLamp, 4), Byte), Integer), CType(CType(CurrentArray(NewLamp, 5), Byte), Integer))
  End If
```

The code above took the values stored for the selected lamp and displayed them in the lamp controls. Later in the code, the background color of the buttons was adjusted to show which lamp had been selected.

4.5.2.1.2.3.4 MODE BUTTONS

The PC Control Console V1.0 has four mode buttons (Manual, Preset 1, Preset 2, Preset 3). When the manual button or preset buttons were pressed the following code was executed:

```
Private Sub BTN_MANUAL_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_MANUAL.Click
    NewMode = "MANUAL"
    Call Change_Mode()
End Sub
```

The system contained two global variables, CurrentMode and NewMode. When a mode button was pressed the NewMode variable was changed to the desired mode. The operation structure and code are displayed below in Figure 18.

```
Private Sub Change_Mode()
    Select Case CurrentMode
      Case Preset1Name
        Preset1Array = CurrentArray
      Case Preset2Name
        Preset2Array = CurrentArray
      Case Preset3Name
        Preset3Array = CurrentArray
      Case Else
    End Select

    Select Case NewMode
      Case Preset1Name
        Me.BTN_PRESET1.Enabled = False
        Me.BTN_PRESET2.Enabled = True
        Me.BTN_PRESET3.Enabled = True
        Me.BTN_MANUAL.Enabled = True
        CurrentArray = Preset1Array
      Case Preset2Name
        Me.BTN_PRESET1.Enabled = True
        Me.BTN_PRESET2.Enabled = False
        Me.BTN_PRESET3.Enabled = True
        Me.BTN_MANUAL.Enabled = True
        CurrentArray = Preset2Array
      Case Preset3Name
        Me.BTN_PRESET1.Enabled = True
        Me.BTN_PRESET2.Enabled = True
        Me.BTN_PRESET3.Enabled = False
        Me.BTN_MANUAL.Enabled = True
        CurrentArray = Preset3Array
      Case "MANUAL"
        Me.BTN_PRESET1.Enabled = True
        Me.BTN_PRESET2.Enabled = True
        Me.BTN_PRESET3.Enabled = True
        Me.BTN_MANUAL.Enabled = False
    End Select

    CurrentMode = NewMode
    NewLamp = "ALL LAMPS"
    Call Change_Lamp()
    Me.Refresh()
  End Sub
```

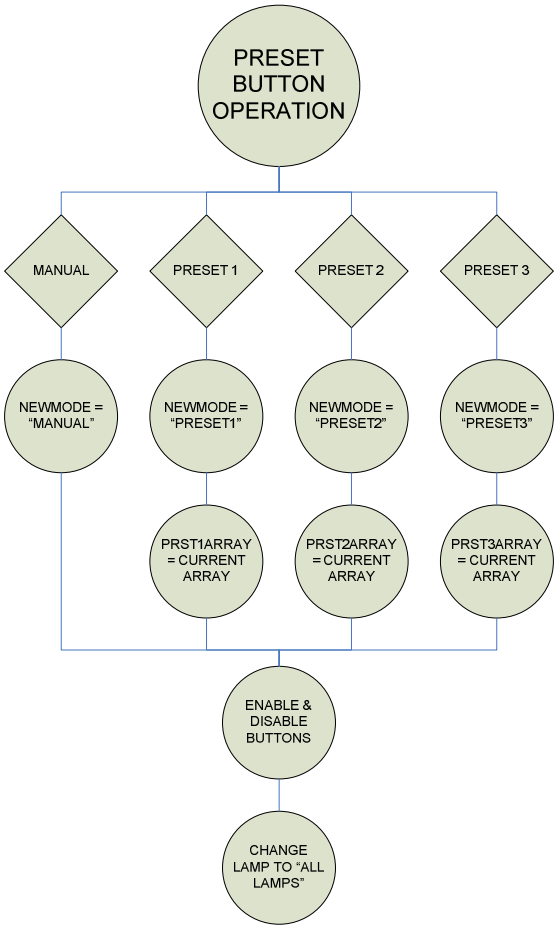

Figure 18 - Mode Buttons Operation and Code

4.5.2.1.2.3.5 SETUP BUTTON

The setup dialog form allowed the user to change some of the program's global variables. In PC Console Version 1.0 only the button names of the Preset1 buttons can be adjusted. This dialog could be expanded to include many other variables as the program grows and expands.

```
Private Sub BTN_SETUP_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles BTN_SETUP.Click
    Setup.Preset1BtnName.Text = Preset1Name
    Setup.Preset2BtnName.Text = Preset2Name
    Setup.Preset3BtnName.Text = Preset3Name
    Setup.ShowDialog()
If Setup.DialogResult = Windows.Forms.DialogResult.OK Then
    Preset1Name = Setup.Preset1BtnName.Text
    Preset2Name = Setup.Preset2BtnName.Text
    Preset3Name = Setup.Preset3BtnName.Text
    Me.BTN_PRESET1.Text = Strings.Left(Preset1Name, 9)
    Me.BTN_PRESET2.Text = Strings.Left(Preset2Name, 9)
    Me.BTN_PRESET3.Text = Strings.Left(Preset3Name, 9)
    Me.Refresh()
End If
End Sub
```

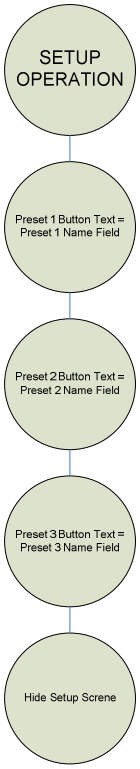
SETUP OPERATION
Preset 1 Button Text = Preset 1 Name Field
Preset 2 Button Text = Preset 2 Name Field
Preset 3 Button Text = Preset 3 Name Field
Hide Setup Screne

Figure 19 - Setup Operation Flow Diagram and Code

4.5.2.1.2.3.6 SCHEDULE BUTTON

The schedule button was one of the most complicated functions in the entire program. The large variability of the recurrence and time frames created the complication. The flow diagram in Figure 20 shows the flow of the schedule program along with the code for the schedule setting operation and the timer elapsed event handling. The recurrence is found in Appendix 10.4.4.

```
Private Sub BTN_SCHEDULE_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles BTN_SCHEDULE.Click
    Schedule.ShowDialog()
    If Schedule.DialogResult = Windows.Forms.DialogResult.OK Then
      If Schedule.Preset1.Checked = True Then
        ScheduleSetting = "Preset 1"
      ElseIf Schedule.Preset2.Checked = True Then
        ScheduleSetting = "Preset 2"
      ElseIf Schedule.Preset3.Checked = True Then
        ScheduleSetting = "Preset 3"
      Else
        ScheduleSetting = "Disabled"
      End If
      If Schedule.Disabled.Checked = False Then
        If Schedule.RecurrenceEnabled.Checked = False Then
          Recurrence = "None"
        Else
          If Schedule.Yearly.Checked = True Then
            Recurrence = "Yearly"
          ElseIf Schedule.Weekly.Checked = True Then
            Recurrence = "Weekly"
          ElseIf Schedule.Monthly.Checked = True Then
            Recurrence = "Monthly"
          Else
            Recurrence = "Daily"
          End If
        End If
        Call SetTimerLength()
      End If
    End If
End Sub
```

Timer Elapsed Event:

```
Private Sub ScheduleTimer_Elapsed(ByVal sender As Object, ByVal e As
System.Timers.ElapsedEventArgs) Handles ScheduleTimer.Elapsed
    If TimerLength = 0 Then
      'Perform Timer Operation and Reset TimerLength
      If ScheduleSetting = "Preset 1" Then
        NewMode = Preset1Name
        Call Change_Mode()
      ElseIf ScheduleSetting = "Preset 2" Then
        NewMode = Preset2Name
        Call Change_Mode()
      ElseIf ScheduleSetting = "Preset 3" Then
        NewMode = Preset3Name
        Call Change_Mode()
      End If
      If Recurrence = "None" Then
      Else
        Call SetTimerLength()
      End If
    End If
    TimerLength = TimerLength - 1
  End Sub
```

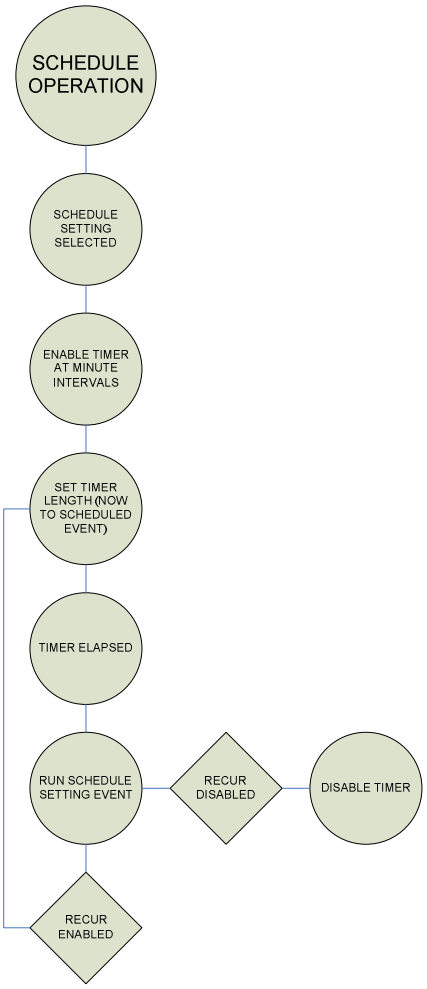

Figure 20 - Schedule Operation Flow Diagram

4.5.2.1.2.3.7 MINIMIZE BUTTON

The minimize button performs the minimize command on the control form window. This button provides the ability for the user to hide the program window and open it up again simply by clicking on it in the windows task bar.

```
Private Sub BTN_MINIMIZE_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_MINIMIZE.Click
    Me.WindowState = FormWindowState.Minimized
End Sub
```

4.5.2.1.2.3.8 HELP BUTTON

The help button opened a help dialog screen. This screen provided the user with a guide on how to operate the program.

4.5.2.1.2.3.9 EXIT BUTTON

The exit button performed two operations. First all of the array and global variable information was stored into the data.txt file. Second the program was exited completely.

```
Private Sub BTN_EXIT_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_EXIT.Click
    Call Save_Data()
    End
End Sub
```

The save data subroutine is show below. It utilizes a series of for statements along with the write command to create the data.txt file.

```
Private Sub Save_Data()
    Dim x, y As Integer
    Dim textdelimiter As String

    ' Create an instance of StreamWriter to read from a file.

    Dim sw As StreamWriter = New StreamWriter(System.AppDomain.CurrentDomain.BaseDirectory & "data.txt")

    textdelimiter = "#"

    sw.Write(UserName & textdelimiter)
    sw.Write(Preset1Name & textdelimiter)
    sw.Write(Preset2Name & textdelimiter)
    sw.Write(Preset3Name & textdelimiter)
    sw.Write(MasterLampName & textdelimiter)

    For x = 0 To 8
      For y = 0 To 10
        sw.Write(Preset1Array(x, y) & textdelimiter)
      Next
      y = 0
    Next
    x = 0

    For x = 0 To 8
      For y = 0 To 10
        sw.Write(Preset2Array(x, y) & textdelimiter)
      Next
      y = 0
    Next
    x = 0


    For x = 0 To 8
      For y = 0 To 10
        sw.Write(Preset3Array(x, y) & textdelimiter)
      Next
      y = 0
```

```
        Next
        x = 0

        sw.Close()
    End Sub
```

4.5.2.1.2.3.10 LAMP CONTROLS

The lamp controls was the heart of the program operation. These set of controls provided the user with the ability to actually control each lamp through various settings. The controls operation flow diagram is shown in Figure 21.

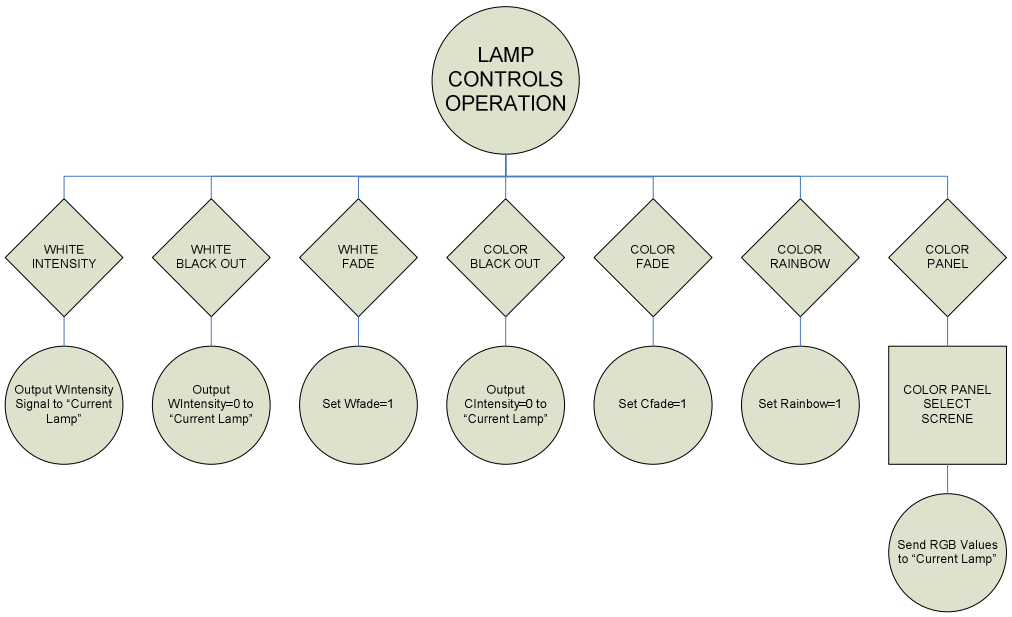

Figure 21 - Lamp Controls Operation Flow Diagram

4.5.2.2 PIC Programs

The LEDmote project needed three different types of programs written for the two different types of microcontrollers. One program, called LEDmote Zigbee Remote Control, was written and programmed onto the remote control processor, the PIC18F4620, which controlled one Zigbee node. The next program, called LEDmote Zigbee Coordinator, was written for and programmed onto the PIC18F4620 program in the lamp base. This program was designed specifically to receive the signals coming from the remote control Zigbee processor. The third program, called LEDmote PWM, was written and programmed onto the original processor, the PIC18F87J10, and its main task was to receive the commands from the Zigbee coordinator and then adjust the pulse width modulation (PWM) of the LEDs accordingly. These three programs will be described more specifically in the following sections[37].

4.5.2.2.1 Constants Defined (Through All Programs)

Some variables needed to be defined from one program to another. These variables were sent and received as instructions from the two Zigbee processors and through the Zigbee Coordinator and the

[37] It may be helpful to refer to Appendix 10.5 and follow the programs through while reading this section.

PWM processor. A different hex number was assigned to each of the different button instructions. The commands that were assigned to each of the buttons are shown below in Table 9.

Table 9 – Button Command Functions

POWER	0x01
WHITE_UP	0x02
WHITE_DOWN	0x03
RED_UP	0x04
RED_DOWN	0x05
GREEN_UP	0x06
GREEN_DOWN	0x07
BLUE_UP	0x08
BLUE_DOWN	0x09
COLOR_UP	0x0A
COLOR_DOWN	0x0B

These constants can be found at the very beginning of every program that was written. The constants were set using the `#define` code, for example to define the Power instruction,

```
#define POWER       0x01
```

These were the only constants that could be found consistently from one program to another.

4.5.2.2.2 LEDmote Zigbee Remote Control Program

This program was based on one of the demo programs that came with the Zigbee Development Kit. The demo program was called DemoRFD, which was written to configure the processor as an end user device. It included all of the initial setup of the Zigbee network and also had some code embedded inside it to output simple commands. To write the Remote Control Program for this project, the DemoRFD program was modified to send out the code that was specific for our remote control.

4.5.2.2.2.1 Constants and Variables Defined in RFD

In addition to the button opcode instructions as described above, the RFD program also had defined constants. After the opcodes were defined, the input ports were assigned to an interrupt constant. The PIC allowed PORT B to be assigned as interrupts. This means that if the processor was set up correctly, it would recognize a change on PORT B and set a flag bit in one of the registers. This would then halt the program. By assigning a constant to these inputs, a more intuitive representation of the interrupt handler routine was possible. An example of how these were set is,

```
#define RB4_INT                 PORTBbits.RB4.
```

PORTBbits.RB4 was found in the header file for the PIC18F4620 that was provided by Microchip. The header file of each processor provides a struct breakdown of each register in the specific processor. So PORTBbits was the variable that was assigned to the entire register that refers to the input/output PORT

B. .RB4 refers to the bit 4 of that register which correlates to the input/output RB4 pin. This was repeated for RB5, RB6, and RB7.

The next section was designated for a structs setup. These made it easier to understand the program because it allowed the defining of one type of variable and then separating that type of variable into different sections. For example, the white flag variable was written as,

```
Static union
{
       struct
       {
       unsigned WhiteUp           : 1;
       unsigned WhiteDown  : 1;
       unsigned None       : 6;
       } bits;
       unsigned char Value;
} WhiteFlag;
```

This takes an 8-bit variable and assigns it a name of WhiteFlag. It then allows that variable to be broken up into its different bits, such as WhiteUp. When this variable is later called, it can be assigned all at once by writing,

```
WhiteFlag.Value = 0x00;
```

This code set all of the bits to zero. A convenient feature of this code format is the capability to assign each bit in the variable an individual value, while leaving the rest of the bits unchanged. To do this, one would simply write,

```
WhiteFlag.bits.WhiteUp = 1;
```

This creation of a struct was used for each of the different variables that were needed: RedFlag, GreenFlag, BlueFlag, and ColorFlag. The use of these variables will be seen later, where they were used to keep track of interrupts if one occurred.

A brief section of calling the different function prototypes was found after the defining of variables and then the main function, which was the real program that runs everything. Even though the main function has been called, some more initialization needs to be done. A function named HardwareInit() was called to run, which was used to initiate the pins to input and output and also enabled other registers that configure the processor to do specific operations.

4.5.2.2.2.2 Hardware Initialization

In the HardwareInit() function, the DemoRFD began by setting the processor in order to talk to the Zigbee processor chip. This essentially means that it was setting the pin directions for the Serial Port Interface. The next section looks at how this function sets up the processor to deal with interrupts.

4.5.2.2.2.3 Interrupt Initialization

Step 1 requires that the interrupt flag bit be cleared. This is done by the line,

```
INTCONbits.RBIF = 0;
```

The first part of this line, INTCONbits., refers to the register INTCON, short for the first Interrupt Control Register. This register was filled with bits and flags that were used to specify which type of interrupt were to be used and also flags that were checked to see if an interrupt had occurred. The second part of the line, .RBIF, refers to a flag bit used for interrupts. RBIF is a flag bit that is set to 1 if a change in PORT RB4:7 has occurred. For example, if RB4 is pushed, input RB4 changes from 1 to 0 and RBIF would then be set to a 1. RBIF was then checked on every clock and if was set to 1, the processor would check a register at location 0x08 to see what it should do.

Step 2 requires that PORTB pull-ups be enabled. This is done by the line,

```
INTCON2bits.RBPU = 0;
```

The first part of the line, INCON2bits., refers to another register that controlled the interrupts. The second part, .RBPU, refers to the bit of that register that enabled the pull-ups for PORT B. This is important because it allowed the processor to correctly read the signals coming into the chip.

Step 3 requires that PORT B is set to an input. This can be done by the line,

```
TRISBbits.TRISB4 = 1;
```

TRIS is the command for any PIC processor that sets the direction of any PORT on the processor. TRISBbits refers to struct that was set up in the header file of the processor and this struct refers to the TRIS of PORT B. The second part of this line, TRISB4, refers to the specific bit of this struct. This line of code set RB4 to an input, because it was set to a 1 (likewise, if it were set to 0, the PORT would then become an output). This concludes the HardwareInit() function, but there are two more steps that must be considered to set up the interrupts that should be discussed here.

Step 4 sets PORTB to be of high priority. This can done by the line,

```
RCONbits.IPEN = 1;
```

This is used more commonly when there are more than one kind of interrupt driven processes in the program. This program contains the Zigbee Interrupts and the PORT B interrupts, both of which are equally important and should be set to the same priority. RCONbits is another register associated with the setup of interrupts. While .IPEN stands for the bit position that corresponds to the enabling of high and low interrupts. If set to 1, PORTB was initialized as high priority. If the bit was set to 0, PORTB would be set to low priority. If PORT B was set to low priority and a change was recognized, the interrupt flag for this change would be set. If the Zigbee interrupt was set to high priority and was also flagged, then the processor would automatically give precedence to the Zigbee interrupt even though it occurred later.

Step 5 requires that all the interrupts to be enabled. This step actually took place outside of the hardware initialization and in the main function because it was important to make sure that the processor did not start looking for interrupts before all other initializations were configured correctly. To do this, the code below was written,

```
INTCONbits.GIEH = 1;
```

Once again, INTCONbits refers to the interrupt control register talked about earlier. Although, this time, .GIEH was used to set a different bit in that register to 1. GIEH stands for Global Interrupt Enable High, which means that the processor would now start looking for any high priority interrupts that were enabled. GIEL is not used here but this bit would be used if it were important to look for any low priority interrupts that are enabled.

At this point, almost all of the initializations had been taken care of. The only remaining initialization was the function call of ZigbeeInit(), which talked to the Zigbee chip through the recently set up SPI port set up in the HardwareInit() function. This was an important initialization but is not talked about in this report because it was assumed that Microchip was initializing the Zigbee correctly and therefore was not researched. Here the processor could now be considered initialized and the main program can be talked about.

4.5.2.2.2.4 main() Function

The majority of this function was done by Microchip who provided the demo program. The interrupts were enabled and then a while loop was started early on in the function. The while loop allowed the program to continually repeat itself and see if any new changes had occurred since the last run through. Right after the while statement, the watchdog timer was cleared. This was important because if it was not cleared, the processor would notice that it reached a certain value and would halt the program because it thought there was a problem. After that was cleared, the main portion of the program began.

The processor went into one big switch statement and checked the value of `currentPrimitive`. This variable was defined by the Zigbee Stack and it was decided that it should not be modified. The variable was assigned different values based on the known progress or step of the program that needed to be performed. After that step was performed, `currentPrimitive` then incremented the proper instruction so the switch statement would do the next instruction in the list on the next run-through.

The whole first part of this function dealt with how the Zigbee RFD connected to the network. The next task of this function was to receive and transmit application specific instructions from one Zigbee module to another. For this project, the program only needed to send transmissions to the Zigbee Coordinator, so the section on how the DemoRFD program sent messages was the most informative section of the entire DemoRFD program supplied by Microchip. It can be found in the section below of the code:

```
// ******************************************************
// Place all processes that can send messages here. Be sure
// to call ZigBeeBlockTX() when currentPrimitive is set to
// APSDE_DATA_request.
// ******************************************************
```

The next step was to write the code that actually sent the wireless transmission to the other Zigbee Coordinator. Some research was done and the code found in the “AN965: Microchip Stack for the

Zigbee Protocol"[38] document was used. This document usefully explained how the demo programs ran and gave more specifics on important instructions used to control transmissions. The section that was referenced for sending messages can be found on page 21 in the AN965[38] document. In this report, only the applicable sections of how to send a transmission will be included, the rest can be found better described in the AN965 document.

The code began with an if statement to check if the processor was not busy and made sure that the Zigbee receiver was not busy by calling function ZigBeeReady(). Another if statement was then added under the first to check what instruction should be sent out. More specifically, this if statement checked to see which flag the interrupt routine had set (See Section 4.5.2.2.2.5). Once a Flag had been recognized, the processor started the routine of sending out a message. The first step of the routine was to clear the interrupt flag. The example below shows how this was done:

```
if( PowerFlag.bits.Power )
{
       PowerFlag.bits.Power = FALSE;
       …
```

As discussed above, this example shows that the power flag was set to TRUE so it would go to this operation. The next line reset the power flag to FALSE so that on the next time around in the while loop, it would not continuously perform this transmission. The next important piece of code that was modified was,

```
TxBuffer[TxData++] = POWER;
```

This line of code sent the constant defined at the very beginning of the program and stored it in the TxBuffer. This buffer was a stack that contained all of the instructions for the Zigbee module to send out. Once this was done, the transmission was sent followed by a few more instructions sent on every transmission that dealt with the destination of the message and the security of the message. More details about the other steps in send the message are found in the AN965 document[39]. An if statement identical to this one was then written for the rest of the interrupt flags that would be detected. This brings us to the end of the modified code and to the end of the main function.

4.5.2.2.2.5 Interrupt Service Routine

The Interrupt Service Routine could be found below the main() function and controlled all the operations if an interrupt occurred. This function is called,

```
Void UserInterruptHandler( void )
```

The first task of this function was to determine if an interrupt had occurred, so an if statement referring to INTCONbits.RBIF was checked, written,

```
if( INTCONbits.RBIF == 1 )
{
       …
```

[38] (Microchip Technology Inc.)
[39] (Microchip Technology Inc.)

As mentioned above in Section 4.5.2.2.2.3, the RBIF was normally set to 0 and if a change was seen on the input PORTB4:7, the flag of that register was set. The next step of the interrupt function was to check and record which input caused the flag. This was necessary because any one of the four inputs could set off this one flag. So another if statement was written, which looks like this,

```
if( RB7_INT == 1 & RB6_INT == 1 & RB5_INT == 1 & RB4_INT == 0 )
       PowerFlag.bits.Power = TRUE;
```

The processor compared the PORT B register to this if statement. This input looked very similar to the defined value of POWER, 0000 0001 in binary, only inverted. That is because the processor was pulled high and recognized a change when an input was pulled to ground (shows a 0). These input codes were generated from the encoder/inverter hardware circuit described in Section 4.5.1.2.2 and 4.5.1.2.3. If the port was different than this one, it would go onto the next line,

```
if( RB7_INT == 1 & RB6_INT == 1 & RB5_INT == 0 & RB4_INT == 1 )
       WhiteFlag.bits.WhiteUp = TRUE;
…
```

The processor went through the rest of the if statements to see if any one of the opcodes could be detected. If one was detected, the processor would go into that if statement and perform the next line. For the above example:

```
WhiteFlag.bits.WhiteUp = TRUE;
```

If this line was called it would set the WhiteUp bit of the WhiteFlag, which would ultimately run the transmission if statement in the main. At the very end of this interrupt function, three more steps had to be performed before the processor could leave this function. The three lines of code were,

```
INTCONbits.RBIE = 0;
LATB = PORTB;
INTCONbits.RBIF = 0;
```

The first line disabled the interrupts on change of the PORTB. This needed to be done because otherwise the processor might start another interrupt of the same kind before it had finished processing the first one. The second line used the LATB register, which cleared any mismatch that might have occurred between PORT B and the reading of the processor value. The third line reset the interrupt on change flag back to zero so that the processor could do other things the next time around the while loop and so that it could detect another interrupt in the future.

4.5.2.2.3 LEDmote Zigbee Coordinator Program

This program, like the RFD, was based entirely on the Demo program that came with the PICDEM Z Development Kit. The program was called DemoCoordinator, and it was capable of setting up a Zigbee network and then being able to send a couple commands across the network. The demo program was rewritten to incorporate the commands that were needed to control the lighting system.

This program was only needed because of how the prototype was designed. This processor was used only to receive the commands from the other Zigbee module, the remote control, and relay the

messages to the PWM Program. If the final design was successful the PWM program would not only control the lights but also be able to send and receive messages from the other Zigbee modules.

Since this program was only designed to relay messages from the remote control to the PWM program, there was no need to add in any other variables or constants that were needed in the Remote Control program. The only constants that were defined in this program were the button opcodes, as were found in the remote control program and later in the PWM program.

4.5.2.2.3.1 UART Initialization

This program required the communication from itself to the PWM program. The UART was selected as the best option for this operation. In order to use the UART, it had to be initialized properly. A function was written specifically to initiate the UART for the proper settings that were needed. This function was called right at the beginning of the main() function and right before the HardwareInit() function was called.

In order to set up the UART, the PIC18F4620 Datasheet[40] was referenced. On page 211, there are specific directions on what registers and bits had to be set to perform an asynchronous transmission. The first step that had to be taken was to setup the Baud Rate of the UART. This could be configured using the table on pg 207, shown below in Table 10.

Table 10 – Baud Rates

BAUD RATE (K)	SYNC = 0, BRGH = 1, BRG16 = 0		
	Fosc = 4.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	-	-	-
1.2	1.202	.16	207
2.4	2.404	.16	103
9.6	9.615	.16	25
19.2	19.231	.16	12
57.6	62.500	8.51	3
115.2	125.000	8.51	1

This table gives a listing of all the different clocks that the processor could be run at, and what were the proper settings for the desired baud rate. The first bit of information that was determined was the oscillator frequency on the PICDEM Z board. This was found by inspection of the board to be 4.00MHz. The desired baud rate that the UART was to be set to was 19200, and in order to get this baud rate, the SPBRG value had to be set to 12. So the follow code was written to do this,

```
TXSTAbits.SYNC = 0;
TXSTAbits.BRGH = 1;
BAUDCONbits.BRG16 = 0;
```

[40] (Microchip Technology Inc.)

```
SPBRG = 0x0C;
```

The first line shown above sets the UART to asynchronous mode by clearing the Synchronous bit in the TXSTA register. The second line allowed the use of a second register to help define the baud rate more clearly. The last line (shown above) finally set the Baud Rate Register to a decimal value of 12, which told the processor to use a 19200 Baud Rate.

After the baud rate had been set, a few more steps needed to be performed before the UART was fully operational. First, the serial port had to be enabled, and to do this the line of code shown below was used.

```
RCSTAbits.SPEN = 1;
```

This enabled the physical input and output of the UART to communicate. The next operation that must be performed was the choice of nine bit mode or eight bit mode. Nine bit mode allowed a ninth bit to be sent to check for errors in the transmissions. For this project, it was decided just to use the standard eight bit mode so the code below was added.

```
RCSTAbits.RX9 = 0;
```

The last setting that needs to be set is,

```
TXSTAbits.TXEN = 1;,
```

This allowed the UART module in the PIC18F4620 to allow transmissions. If this was not set to high the processor would never send out a transmission. However, if set high, the processor would recognize that it needed to send a transmission once the transmission register was full. This completed the initialization of the UART and allowed for the processor to send data to the Pulse Width Modulation Processor.

4.5.2.2.3.2 Hardware Initialization

The hardware initialization of the Coordinator Program contained a lot of the same steps as the Remote Control Program did. It started out again with all of the predefined initialization of the SPI ports for the Zigbee Daughter Card, making sure that the two processors were able to communicate. The next thing that was initialized was PORT A bit 0. This was set to an output so that the program would allow the user to see an LED on the development board to flash when it received a transmission. This was done by the line,

```
TRISA = 0xE0;
```

This was about all that had to be initialized on the hardware side of things. There was no additional interrupt initialization apart from Zigbee because this program was only used to receive the signals from the remote control and relay those to the PWM Processor.

4.5.2.2.3.3 main() Function

Once everything was initialized properly, the main function of the program could begin. Once again, a lot of this program was left from the demo program that it was based on. The whole first part of the

main function consisted of setting up a Zigbee network. Once the network was set up, the Coordinator Program could start looking for messages from the other devices in the network. If the coordinator received a transmission from the remote control and it had the device ID of EP_LIGHT, the Coordinator Program would process the command. This was done in the switch statement that started like this,

```
switch (params.APSDE_DATA_indication.DstEndpoint)
{
       case EP_ZDO:
       …
       case EP_LIGHT:
       …
```

Once the program recognized that it was supposed to perform the command it had just received, it began to process what it had to do. The program went through a couple more steps to collect the data and then entered another switch statement that deciphered what code it has just received and needed to perform.

```
data = APLGet();
switch (data)
{
       case POWER:
              WriteUSART( POWER );
              MESSAGE_INDICATION ^= 1;
              TxBuffer[TxData++] = SUCCESS;
              break;
       …
```

The first line shown above uses the `APLGet()` function to pull the data off of the Zigbee Transciever and then set it to a variable data. The variable data was then processed into a switch statement to decode each instruction. In the first case shown above, it could be seen that the Coordinator Program immediately takes the data received and puts it on the UART transmit register for it to be relayed to the PWM Program, using the `WriteUSART()` function. The next line simply changed the LED on the development board to alert the users that it had successfully received and transmitted the message to the other processor. The seventh line shown above sent a message back to the remote control, letting it know that the message was received properly. Once done with the message handling the case statement was broken and waited for another transmission to be received.

4.5.2.2.4 LEDmote PWM Program

This program was written for the main purpose of controlling the outputs of the LEDs. It communicated through a UART connection to the Zigbee Coordinator chip, which relayed the signals from the remote control. At the beginning of the project, it was decided that this program would control all the light modulation and Zigbee communications. But due to some problems discussed earlier it was decided that this program would only do the PWM outputs.

4.5.2.2.4.1 Constants and Variables Defined in PWM Program

The PWM Program has extra Constants defined that the other two programs lack because of the pulse width modulation handling. The program started out the same way defining the opcode instructions which were just the same as the other two programs. The next defined constant was used to set the period for the pulse width modulation, this was shown below.

```
#define PERIOD_INITIAL                  0xFF;
```

The initial period was set to 0xFF because this was the largest period that it could be set to. This allowed for the maximum amount of adjustment of the LED brightness. If it were really small, the LEDs would flicker so fast that a large change in the duty cycle would not be seen by the naked eye. The next set of constants define the initial conditions for the duty cycles.

```
#define W_INITIAL                       500
#define R_INITIAL                       500
#define G_INITIAL                       700
#define B_INITIAL                       300
```

These values could be set from a range of 0 to 900 depending on the initial condition that was wanted. With the settings shown above, the white LEDs were set to half power and the mixture of the red, green and blue that was chosen would turn the lamp a nice shade of green. Next, a set of minimum and maximum constants were defined.

```
#define DC_MAX                          900
#define DC_MIN                          75
```

The values were set based on a few tests performed on the pulse width modulation outputs. When the duty cycle was constantly turned up, the pulse would roll over back to zero creating an malfunction in the operation of the light. The light would roll over close to a duty cycle of 1000 so a maximum value was set to 900 so that it would not create a problem. The minimum was set to 75, also to prevent a malfunction when turning the LEDs down. However, it was found that when the duty cycle was turned all the way down, it would not malfunction and simply just bottom out. This could have been excluded but was left in case of a future error. The last set of constants defined were

```
#define W_CHANGE                        75
#define R_CHANGE                        100
#define G_CHANGE                        100
#define B_CHANGE                        100
```

This set of constants would ultimately determine how many different colors the light could produce. With the defined period talked about above, it allowed the duty cycle to be set from 0 to 1000. The change constants define how many steps the colors would change. With the color change set to 100 there were 10 different steps for each individual color. The two constants after these changed definitions were used for the UART and allowed it to check if data was ready to be received or not.

4.5.2.2.4.2 USART Initialization

This function is similar to the USART Initialization in the Coordinator Program. Although this UART has to primarily receive transmissions from the Coordinator Program so it is set up differently. Also, this function must be set up for two UARTs, one for the Coordinator Program and one to communicate with the Bluetooth module. It starts out the same as the UART function in the Coordinator Program with the setup of the Baud rate for the first UART.

```
TXSTA1bits.SYNC = 0;
TXSTA1bits.BRGH = 0;
BAUDCON1bits.BRG16 = 0;
SPBRG1 = 0x07;
```

The SPBRG value for this one is different because it was discovered that the HPC Board uses a 10Mhz oscillator. Table 11 below was found in the PIC18F87J10 Datasheet. Again, a value for the SPBRG1 had to be chosen so that the baud rate would be 19200.

Table 11 – Baud Rates

BAUD RATE (K)	SYNC = 0, BRGH = 0, BRG16 = 0 Fosc = 10.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	-	-	-
1.2	1.202	.16	129
2.4	2.404	.16	64
9.6	9.766	1.73	15
19.2	19.531	1.73	7
57.6	52.083	-9.58	2
115.2	78.125	-32.18	1

Now the baud rates for the two programs were set to be the same and could communicate properly once data was sent. The rest of the UART was set up in the next few lines.

```
RCSTA1bits.SPEN = 1;
RCSTA1bits.RX9 = 0;
RCSTA1bits.CREN = 1;
```

The serial port was enabled on the first line shown above. This line of code refered to the RCSTA1 register. The 1 in the name allowed the processor to distinguish between the two different UARTs in the processor. The next line of code above set this UART to eight bit mode and the line under that was the most important. CREN stands for Continuous Reception. This allowed the processor to always look for data in the UART receive register, as opposed to setting it to single reception where the UART would have to be reset after every reception.

The next step in the function was to set up the second UART for the Bluetooth module communication. The baud rate was set up identically because the Bluetooth module also used a baud rate 19200. The rest of the UART was set up the same way except that the transmitter had to be enabled as well. This was done by the line,

```
TXSTA2bits.TXEN = 1;
```

After this was set, both the UARTs in this processor were set up and fully capable of communicating to the other two processors.

4.5.2.2.4.3 Hardware Initialization

The hardware initialization function was then called in the main program to initiate any other application necessary settings. For this program, the initialization was very short because PWM were set up in the actual main function and not in the hardware initialization. The only code that was in the function was,

```
TRISD = 0x00;
```

This code allowed PORT D to become outputs, which would be later used for outputs as test LEDs. Now that everything was initialized the main function could resume.

4.5.2.2.4.4 main() Function

The first thing that the main function did was turn one of the LEDs on so that the user would know that the program was running whenever the LED lit up. This was done by the line,

```
PORTD = 0x01;
```

The next thing that the program did was set the power_status variable to 0. This let the program know that the power of the lights was off. Later, it would be seen that this bit was toggled back and forth depending if the lights are on or off. Next, the program went into a while loop that allowed the program to continually check if any new receptions had come from the Coordinator Program. The first few lines dealt with getting the information from the UART.

```
char inputstr[1];
opcode = 0x00;
gets1USART( inputstr, 1 );
opcode = inputstr[0];
```

The first line created a character array for the data that was pulled off of the reception register and stored in positions in the inputstr array. The gets1USART() function probably was one of the most important functions of the program . It was originally written by microchip and found in some of the example code that came with the MPLAB C18 Compiler. It also was also referenced in the MPLAB C18 Library document. The first variable sent to this function was inputstr, which told the function where to store the data. The second variable sent to the function told it how much data it should copy into the array. For this case, the Coordinator Program was only sending it one Byte of instruction, so only one Byte had to be stored into the inputstr array. The last line of code listed above set the opcode variable to whatever data is stored in the first position of the inputstr. This was the Data received from the UART.

The next step was to decipher what opcode was received from the UART. This was done by loading the opcode value into a switch statement.

```
switch( opcode )
{
       case POWER:
              if( power_status == 0 )
              {
                     power_status = 1;
                     …
              }
              else
              {
                     power_status = 0;
                     …
              }
              Break;
}
```

Above is the general switch statement of how the program worked and how the PWMs was used. If the opcode equaled the POWER constant, then it would go into the case statement shown above. The first thing that this case statement did was check if the light was on or off. If equal to zero, the program would set the power_status variable to 1 and then proceed to turn the LEDs on. The program turned on the LEDs by using three functions that were also found in the MPLAP C18 Library document. First, the PWM outputs were initialized by calling the OpenPWMx() command. This would set up all the need hardware for the PWM to be outputted. It also set the period of the PWMs. Second, some special initialization had to be done for the PWM 1, 2, and 3 because they were specified as special outputs for the processor. The function that set up these special PWM outputs was SetOutputPWMx(). Lastly, the duty cycle had to be set in order for the pulse width modulation to work. SetDCPWMx() was the function that was responsible for this. This function received the duty cycle that was specified and overwrote the old one. After this function was called, the PWM outputs were operating.

If the power_status equalled 1, the program recognized that the light was on and then would go into the else statement. The first step of this statement reset the power_status variable to zero. The else statement then proceeded to close the PWM outputs by calling another function from the MPLAB C18 Library, the ClosePWMx(). This function did all the operations needed to stop the outputs of the pulse width modulation.

Now if the opcode equalled RED_UP, the program entered a different case statement as shown below.

```
Case RED_UP:
{
        if( pwm1_dc >= DC_MAX );
```

The first thing that this case statement did was check to see if the duty cycle was already maxed out. If it was, the program simply exited the case statement and did not change the duty cycle. If it was less than the specified DC_MAX constant then the program would proceed to increase the duty cycle. It did this by adding the change constant to the dc_pwmx variable and then called on the SetDCPWMx() function again, which overwrote the last duty cycle with the new increased one. This same sort of operation was done for the rest of the UP opcodes and also for the DOWN opcodes by subtracting the CHANGE constants for the duty cycles. After the proper case statement had been performed, the program waited for another UART transmission to be received.

5 Business Plan

5.1.1 Business Opportunity

There are many lighting products currently available in commercial industry. A corporation has thousands of lamps to choose from in order to meet their needs. In order to enter an industry with hundreds of established suppliers, you must offer a product that is unique to the industry. The product that team LEDmote was aiming to develop did this in several ways. LEDmote used new LED technology in its lamp modules, providing customers with high clarity pure white light at a very low power. The LED cells lasted longer and burned cooler than regular lighting methods in the current market, greatly improving efficiency. Team LEDmote's project incorporated multicolor accenting effects and a wireless

control system giving customers more freedom and more control over their lighting environment from their computer or remote control. Mood lighting is easily accessible for conference rooms, depending on the presentation. The conference room lighting system will be packaged as an easily expandable 4 lamp system with a remote control. The number of lamps will depend on the room size. The remote will be operational as long as it is within 30 feet of any lamp. The computer must be within 30 feet of the master lamp in order to be operable. The lamps will output 500 lumens which is equivalent to a 60 watt light bulb. Taking these factors into consideration will determine the number of lamps needed per room. Providing all these features at the market price of the average product on the market today is a great business opportunity.

5.1.2 Industry Environment

5.1.2.1 Overview of the industry

The commercial lighting fixture industry manufactures electric lighting fixtures for commercial, industrial, and institutional customers. About 80 percent of industry output in 1997 was used for commercial and institutional purposes. This characterized the market for the LEDmote family of products. As of 1997, about 320 companies competed in the commercial lighting fixture industry. Of these, only a handful of companies have achieved over 400 million dollars in sales each. The demand in the US lamp industry is in the area of 6.5 billion units a year total[41]. With such a high market demand and a diverse group of suppliers the market entry should not be difficult.

5.1.2.2 Projected position for the future

The first product release will involve conference room lighting and desk lighting. The circuitry is being designed to accommodate other applications with as little adjustment as possible. This provides the opportunity to bring the wireless LED lighting concept to other residential and institutional consumer industries.

5.1.2.3 Potential customers

The commercial and industrial sectors are the primary potential customers of the LEDmote product family. The series of products will be designed and priced mainly for use in conference rooms and offices. The price of the product will limit its use in residential settings, though residential applications are not out of the question. The software will be designed for a windows based systems. Currently 93% of corporate operating systems are running Microsoft Windows based systems42 (Figure 22).

---

[41] Standard and Poors Corporation. Standard & Poor's industry surveys Standard and Poors Corporation, New York. July 1997.

[42] Net Applications. *Operating System Market Share*. November 2006. <http://marketshare.hitslink.com/report.aspx?qprid=2>

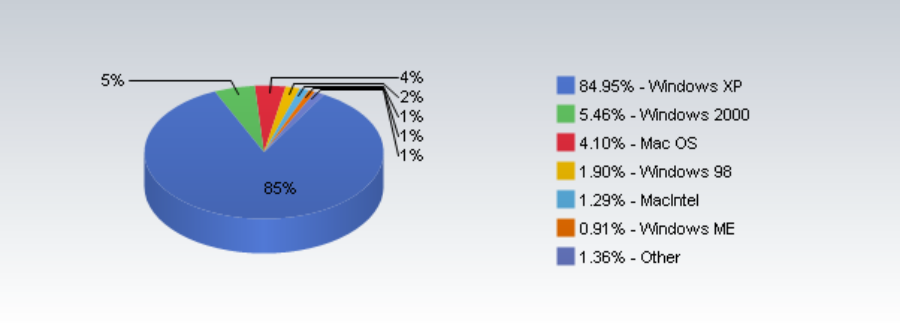

Figure 22 - Corporate Operating System Market Share

5.1.3 Marketing Strategy

See supportive "LEDmote MARKETING PLAN".

5.1.4 Operations

5.1.4.1 Capital Requirements

Table 12 - Product Launch Costs

Part Name	Price/Unit	Quantity	Unit Price
Prototype Materials	$ 2,384.79	1	$ 2,384.79
Engineering Design Time	$ 100.00	1200	$ 120,000.00
Engineering Line Design	$ 250,000.00	1	$ 250,000.00
Productioon Line Build	$1,500,000.00	1	$1,500,000.00
Patent Fees	$ 5,000.00	1	$ 5,000.00
		TOTAL COST:	$1,877,384.79

The capital requirements for the launch of this product are shown in Table 12. The capital requirements were high due to various factors such as the production line build. The equipment needed to support the LEDmote manufacturing line was quoted at 1.5 million dollars. This did not included the engineering line design time of $250,000. The breakdown of the prototype cost ($2,384.79) is shown in Table 13. Given the launch costs, they will be amortized over a three year adjusted span. The annual amortization expense is shown in Table 14.

Table 13 - Prototype Costs

Description	Price
Microchip Zigbee Protocol	$ 270.00
New ark Parts	$ 12.19
Digi-Key Parts	$ 30.67
Mouser Parts	$ 31.34
Stencils Unlimited	$ 344.00
Mouser Parts	$ 15.62
Arrow Electonric	$ 291.15
Microchip Part	$ 20.07
Microchip Part	$ 29.75
Digi-Key Parts	$ 425.00
Advanced Circuits	$ 390.00
Sunstone Circuits	$ 525.00
GRAND PROJECT TOTAL	$ 2,384.79

SPONSORSHIPS:			
Calvin College	$	300.00	
Sunstone	$	350.00	
Advanced Circuits	$	390.00	
Total Sponsoships			$(1,040.00)
		External Project Expense:	$ 1,344.79

Table 14 - Product Launch Annual Amortization Schedule

1st Year (50%):	$ 938,692.40
2nd Year (30%):	$ 563,215.44
3rd Year (20%):	$ 375,476.96

5.1.4.2 Core operations

The product will be assembled and packaged through in-house operations. Sales will not be conducted directly with customers; instead product will be distributed through various industrial and commercial suppliers. Using national and international commercial and building suppliers will provide visibility for the product line. Outsourcing for complex parts such as the PCB board will allow for lower launch costs along with low productions costs.

5.1.5 Financial Projections

5.1.5.1 Market Price Research

Market research was conducted on current market LED desk lamps and conference room lighting products. The research included various suppliers in order to diversify and obtain a realistic market price for the LEDmote products. The average retail price of LED desk lamps is $133.75 with a standard deviation of $69.73 (LEDmote Marketing Plan). Since the desk lamp is a high volume product, the analysis assumes a 50% retailer markup from the production price. The manufacturing sale price is $89.17 and will be used for the remaining financial analysis.

The average retail price of conference lights is $360.21 with a standard deviation of $97.21 (LEDmote Marketing Plan). The conference lights are a specialty product with a typical retailer markup around 80%. The manufacturing sale price is $200.11 and will be used in the remaining financial analysis.

5.1.5.2 Production Cost Analysis

The desk lamp production cost breakdown is shown in Table 15 below. The lamp fixture itself contains LEDs, material and miscellaneous components. Team LEDmote is not designing the fixture itself so the material component price aspect is an estimate based on Innotec's input. The lamp controls pricing section consists of the Bluetooth and FPGA device along with various other minor components. A miscellaneous components section is included to account for parts that have not yet been accounted for. Finally labor, shipping, packaging is included into the price giving a total cost of $72.98 per unit sold.

Table 15 - Desk Lamp Cost Analysis

Part Name	Price/Unit	Quantity Per Unit	Unit Price
LAMP FIXTURE:			
Components *(Table 18)*	$ 18.67	1.00	$ 18.67
Material	$ 7.50	1.00	$ 7.50
	TOTAL LED FIXTURE EXPENSE:		$ 26.17
LAMP CONTROLS:			
Components *(Table 20)*	$ 49.07	1.00	$ 49.07
	TOTAL LAMP EXPENSE:		$ 49.07
TYPICAL NUMBER OF COMPONENTS PER UNIT:			
Lamp Fixture:	$ 26.17	1.00	$ 26.17
Labor:	$ 12.00	0.04	$ 0.48
Packaging:	$ 1.50	1.00	$ 1.50
Shipping:	$ 2.50	1.00	$ 2.50
Lamp Controls:	$ 49.07	1.00	$ 49.07
	TOTAL COST OF GOODS SOLD:		$ 79.72

The conference lighting production cost breakdown is shown in Table 16 below. The lamp fixture itself contains LED, material and miscellaneous components. Team LEDmote is not designing the fixture itself so the material component price aspect is an estimate based on Innotec's input. It is higher than the desk lamp given the built-in aesthetics that will be required and the size of the conference room lamp fixtures. The lamp controls pricing section consists of the Zigbee transceiver, FPGA device, minor components and one fourth of the Bluetooth module cost. A miscellaneous components section is included to take into account for parts that we did not account for in the design. We are assuming that the typical conference room will have one remote, one mother lamp with dual wireless technologies (i.e. Zigbee and Bluetooth) and three slave lamps. Therefore the single unit cost includes one fourth of the remote and Bluetooth module. Finally labor, shipping, packaging, and one forth remote cost are included into the price giving a total cost of $76.29.

Table 16 - Conference Room Cost Analysis

Part Name	Price/Unit	Quantity Per Unit	Unit Price
LAMP FIXTURE:			
Components *(Table 18)*	$ 31.96	1.00	$ 31.96
Material	$ 15.00	1.00	$ 15.00
	TOTAL LED FIXTURE EXPENSE:		$ 46.96
LAMP CONTROLS:			
Master Components *(Table 19)*	$ 49.07	0.25	$ 12.27
Slave Components *(Table19)*	$ 30.64	0.75	$ 22.98
		TOTAL LAMP EXPENSE:	$ 35.25
REMOTE COSTS:			
Components	$ 22.35	1.00	$ 22.35
		TOTAL REMOTE EXPENSE:	$ 22.35
TYPICAL NUMBER OF COMPONENTS PER UNIT:			
Remote:	$ 22.35	0.25	$ 5.59
Lamp Fixture:	$ 46.96	1.00	$ 46.96
Labor:	$ 12.00	0.04	$ 0.48
Packaging:	$ 1.00	1.00	$ 1.00
Shipping:	$ 2.00	1.00	$ 2.00
Lamp Controls:	$ 35.25	1.00	$ 35.25
		TOTAL COST OF GOODS SOLD:	$ 91.27

5.1.5.3 Projected Income Statements

Table 17 - Annual Sales Projections

	Year 1	Year 2	Year 3
Desk Lamp:	30,000	60,000	80,000
Conference Room:	4,000	8,000	11,000

The annual sale projections are derived from the market research in the LEDmote marketing plan. The projected first year sales are 34,000 units, a conservative .0007% of industry market share (Table 17).

The income statement for the initial year (Table 18) of production was created using the financial analysis in the previous sections. The marginal revenues of the products are 10.5% and 54.5% for the desk lamp and conference room respectively. The launch expense is amortized over an adjusted three years. The selling expense was calculated with a $100,000 base + $0.70 per unit sold for sales person salary and advertising expenses. The maintenance and insurance costs are rough estimates. The warranty expense assumes a 4% claim rate on the products sold. The cost of the replaced products was calculated into this warranty expense. The first year of production show a net loss of $291,240.22, which is typical for an initial product launch.

Table 18 - First Year Projected Income Statement

LEDmote

PRODUCT LAUNCH INCOME STATEMENT

FIRST YEAR STATEMENT

DESK LAMP:				Marginal Revenue
Number of Units:	30,000.00			10.59%
Sales:				
Price Per Unit:	$ 89.17			
Desk Lamp Revenue:		$ 2,675,046.15		
COGS:		$(2,391,691.20)		
Desk Lamp Net Income:			$	283,354.95
CONFERENCE ROOM:				Marginal Revenue
Number of Units:	4,000.00			54.39%
Sales:				
Price Per Unit:	$ 200.11			
Conference Room Revenue:		$ 800,456.30		
COGS:		$ (365,098.61)		
Conference Room Net Income:			$	435,357.69
OVERHEAD EXPENSES:				
Launch Amortization Expense:		$ (938,692.40)		
Selling Expense:		$ (123,800.00)		
Maintenance Expense:		$ (25,000.00)		
Insurance:		$ (10,000.00)		
Warranty Expenses:		$ (106,620.61)		
Total Expenses:			$	(1,204,113.00)
NET INCOME BEFORE TAXES:			$	(485,400.36)
Income Tax:			$	194,160.14
NET INCOME:			$	(291,240.22)

The second year income statement (Table 19) was created using the financial analysis from the research and projections in the previous sections. The number of units sold increased from the previous due to product exposure and advertising. The projected second year sales are 68,000 units, still a conservative .00105% of industry market share (Table 17). The sale price of the units was decreased by 5% to account for inflation and keep the product competitive. The marginal revenue percentage of the desk lamp is 6%. The marginal revenue percentage of the conference room is 52%. The second installment of the launch amortized expense is reflected along with a selling expense calculated with a set $100,000 base fee + $0.60 per unit sold for sales person salary and advertising expenses. The warranty expense assumes a 4% claim rate on the products sold. The cost of the replaced products was calculated into this warranty expense. Additionally the company begins to expense R & D to cover the development of new products in order to remain competitive. The product line will produce a net profit of $3,329.58 in its second year.

Table 19 - Second Year Projected Income Statement

LEDmote

PRODUCT LAUNCH INCOME STATEMENT

FIRST YEAR STATEMENT

DESK LAMP:			Marginal Revenue	
Number of Units:	60000		5.9%	
Sales:				
Price Per Unit:	$ 84.71			
Desk Lamp Revenue:		$ 5,082,587.69		
COGS:		$ (4,783,382.40)		
Desk Lamp Net Income:			$	299,205.29
CONFERENCE ROOM:			Marginal Revenue	
Number of Units:	8000		52.0%	
Sales:				
Price Per Unit:	$ 190.11			
Conference Room Revenue:		$ 1,520,866.96		
COGS:		$ (730,197.22)		
Conference Room Net Income:			$	790,669.74
OVERHEAD EXPENSES:				
Launch Amortization Expense:		$ (563,215.44)		
Selling Expense:		$ (140,800.00)		
Maintenance Expense:		$ (25,000.00)		
Insurance:		$ (10,000.00)		
Warranty Expenses:		$ (213,241.21)		
R & D Expenses:		$ (132,069.09)		
Total Expenses:			$	(1,084,325.74)
NET INCOME BEFORE TAXES:			$	5,549.29
Income Tax:			$	(2,219.72)
NET INCOME:			$	3,329.58

The third year income statement (Table 20) was created using the financial analysis from the research and projections in the previous sections. The number of units sold increased from the previous terms due to product exposure and advertising. The projected second year sales are 91,000 units, still a conservative .00169% industry market share. The sale price of the units is decreased by 10% from the original price to account for inflation and to keep the product competitive. Additionally the cost of goods sold was decreased by 5% to account for improvements in production efficiency and decrease in component costs. The marginal revenue percentage of the desk lamp is 5.5%. The marginal revenue percentage of the conference room is 52%. The final launch expense amortized along with a selling expense was calculated with a $100,000 base + $0.50 per unit sold for sales person salary and advertising expenses. The warranty expense assumed a 3% claim rate on the products sold. The claim rate is decreasing due to more efficient processes and decrease PPM. The cost of the replaced products is calculated into this warranty expense. The company continues the R & D expense to cover the development of new products in order to remain competitive. The product line produces a net profit of

$177,132.25 in the third year. The third year final statement reflects closely the sustainable income from this product line into the future years.

Table 20 - Third Year Projected Income Statement

LEDmote
PRODUCT LAUNCH INCOME STATEMENT
THIRD YEAR STATEMENT

DESK LAMP:				Marginal Revenue
Number of Units:	80000			5.6%
Sales:				
Price Per Unit:	$ 80.25			
Desk Lamp Revenue:		$ 6,420,110.77		
COGS:		$ (6,058,951.04)		
Desk Lamp Net Income:			$	361,159.73
CONFERENCE ROOM:				Marginal Revenue
Number of Units:	11000			51.9%
Sales:				
Price Per Unit:	$180.10			
Conference Room Revenue:		$ 1,981,129.33		
COGS:		$ (953,820.12)		
Conference Room Net Income:			$	1,027,309.21
OVERHEAD EXPENSES:				
Launch Amortization Expense:		$ (375,476.96)		
Selling Expense:		$ (145,500.00)		
Maintenance Expense:		$ (25,000.00)		
Insurance:		$ (10,000.00)		
Warranty Expenses:		$ (221,455.93)		
R & D Expense:		$ (252,037.20)		
Total Expenses:			$	(1,029,470.09)
NET INCOME BEFORE TAXES:			$	358,998.85
Income Tax:			$	(143,599.54)
NET INCOME:			$	215,399.31

6 Project Management

6.1 Team Management

The team was organized with no designated leader but with a "top rocks" system to ensure accountability. Such a system is used by Innotec and other companies. It works by having each member work on a small daily task which they list on a whiteboard. At each top rocks meeting, the individuals are asked how they have progressed on their task and, if incomplete, what they need to get it done. The team helped each other out a lot during the project with the result that while one person may have been focusing on a large aspect of the project, they were often supported at various times by one or more other team members.

6.1.1 Chris Kreft

During the first semester, Chris was responsible for researching and selecting from the amplifier alternatives. He was also responsible for deciding on how centralized or distributed the power and control systems would be and the layout for the remote control. He was also responsible for writing sections of the PPFS. During the second semester, Chris initially did research on switch mode power supplies. Ultimately, however, the team decided that due to time constraints they would purchase rather than build a power supply. Chris checked over the layout of the control lamp base layout before printing and worked with Dustin and Dan to solder parts to the boards. Chris also worked on the PIC microprocessor and wrote a "Hello World" test program in assembly code, laying a foundation for Ryan's software work. Chris designed, built and tested the PCBs for the button array and the amplifier in the secondary plan. Chris was also responsible for ordering parts, researching parts for the LED array, working with Dustin on the initial LED array, hardware testing, two presentations and helping write up the final report.

6.1.2 Dan Prince

During the first semester, Dan researched wireless protocols. After the team determined that the Zigbee protocol would be used, it was Dan's responsibility to create a schematic for the Zigbee transceiver and surrounding circuitry. After the PCBs were laid out, Dan spent his time ordering parts until this task was completed. Following the receipt of parts, Dan began researching and learning PIC microcontroller programming and software. Next, Dan began testing and debugging PCBs. This was followed by Zigbee protocol research and setup of Zigbee transfers using PIC software. While continuing experiments with Zigbee, Dan worked on the amplifier circuit and button circuit. The semester was completed with setup for design night and completion of the final report.

6.1.3 Ryan Truer

During the first semester Ryan started to research different Bluetooth Modules and the overall set up of a Bluetooth device. He was then assigned to pick out a Bluetooth Module that was used for the project. After that was done, Ryan began to make the schematics in Eagle of all the PCBs. He then designed the four layer board for the Lamp Base. After the PCBs were ordered he began looking into how the PIC processors were programmed. When the boards came back after the rest of the team had finished soldering the boards, Ryan began to debug the boards with Dan and tried to figure out what was wrong with them. When those were determined not worth trying to fix, he began searching for a second option and decided to purchase the PICDEM Z development kit in order to get the prototype working. After this decision was made Ryan began to start writing all of the code for the PIC Processors. During this time he helped out various team members with some of the hardware issues.

6.1.4 Dustin Veldkamp

During the first semester, Dustin researched the business plan along with the LED array. Dustin created a worst-case analysis for the components for the LED array. Parts were ordered using the values determined by the worst-case analysis. It was Dustin's responsibility to create the schematics for the LED array and remote circuit. He also designed and ordered the printed circuit boards for both schematics. After the PCBs were laid out, Dustin spent his time researching the business plan for the project. Following the receipt of parts, Dustin began soldering and assembling all the circuits boards at

Innotec. Next, Dustin began researching the PC software. Once the software protocol was chosen, he designed the PC user interface. The semester was completed with setup for design night and completion of the final report. .

6.2 Schedule

The team set a very aggressive schedule as advised by the team mentor at Innotec. This aggressive schedule was set up around a few key events. The "Milestones" Microsoft Project file is shown in Section 10.1. The milestones began with February due dates for the design of the hardware. This included design of the circuits and layout of PCBs. The hardware design went a little behind schedule, delaying the team a week. After finishing preliminary hardware design, the team moved on to software design. This was planned to fill the void between ordering and receiving hardware. The hardware was received in time for spring break, so much of that week was spent soldering and testing. Unfortunately, we were unable to get working hardware by March 30, as set in the schedule. After a few extra weeks of debugging beyond March 30, it was decided that the team would move to the backup plan and work on getting a prototype working on development kits. At this point, the team shifted its major focus to the development of working software. As shown in the "Milestones" schedule, the plan was to have a working and tested prototype a full two weeks before the final presentation of the project. These two weeks would then be dedicated to rounding out the project and finalizing the documentation aspects of the project. Unfortunately, setbacks caused those two weeks to be used in trouble shooting and problem analysis, so the schedule was not followed completely.

6.2.1 Task Specification

The team was able to determine an estimate for the hours spent on Senior Design this semester from the Microsoft Project file, "Milestones" (Section 10.1). The estimated hours are shown in the project forecast, Table 21. The estimated hours were determined by multiplying the number of weeks before a task by 80 hours for each week (20 hours per team member a week). This gives a total estimate of 1120 hours for the 14 weeks of the semester.

Table 21 - Project Forecast

Milestone	Start Date	Weeks	Milestones	Estimated Hours
1	2/9/2007	2	Schematic Layout	160
2	2/16/2007	1	Circuit Board Layout	80
3	2/23/2007	0.5	Order Boards	40
4	3/30/2007	3	Working/Tested Hardware	240
5	4/13/2007	2	Working/Tested Software	160
6	4/20/2007	3	Working/Tested Prototype	240
7	5/5/2007	2	Senior Design Banquet	160
8	5/7/2007	0.5	Project Review	40
Totals		14		1120

Actual hours were kept on a timesheet by each team member throughout the year. Every hour spent on senior design was recorded as well as what task was worked on during that time.

Table 22 - Actual Hours

Milestone	Task	Chris	Dan	Ryan	Dustin	Total
1	Design Review	5	18.5	10	5	38.5
1	Remote Design	13	5	12.5	0	30.5
1	Power Supply	12	0	0	5.5	17.5
1	Bluetooth Design	5	1.5	63	12	81.5
1	Zigbee Design	0	65.7	4.75	0	70.45
1	LED Array/ Lamp Design	0	0	0	57.1	57.1
1	Microcontroller Design	0	0	1	18.5	19.5
1	Scheduling	0	14.1	1.5	0	15.6
2	PCB Design	36.5	0	88	28	152.5
3	Order Parts	30	35.5	4	28.5	98
4	Drill/Solder PCBs	22	13	7.5	37.5	80
4	Amplifier Circuit	9.5	8	2	0	19.5
5	PIC Software	40	45	125	0	210
5	PC Software	0	0	0	67.5	67.5
6	Miscellaneous Testing and Debug	10	32.5	39.5	0	82
7	Final Report	28.5	80	8	51.6	168.1
7	Design Night and Prep	20.5	12.5	20.5	8	61.5
8	Meetings/ Conference Calls	9	8	3	4	24
9	Class	18	18.5	16.85	15.5	68.85
9	Presentations/ CEAC	17	9.5	6	1.5	34
Totals		271	348.8	403.1	335.2	1396.6

These hours were then funneled into 20 different tasks, which were each assigned a milestone. The 8 milestones are shown in Table 22. With this method, the team could compare the actual hours to the estimated for each milestone.

Table 23 - Comparison Table

Milestone	Milestones	Actual	Estimate	Difference
1	Schematic Layout	330.65	144	-186.65
2	Circuit Board Layout	152.5	72	-80.5
3	Order Boards	98	36	-62
4	Working/Tested Hardware	99.5	216	116.5
5	Working/Tested Software	277.5	144	-133.5
6	Working/Tested Prototype	82	216	134
7	Senior Design Banquet	229.6	144	-85.6
8	Project Review	24	36	12
9	Overhead Hours	102.85	112	9.15
Totals		1396.6	1120	-276.6

Table 23 shows the variation between the estimated and actual hours. The estimate column uses 90% of each milestone's hours for the estimate and 10% is left over for the overhead hours row. Class and

Presentations/CEAC fall under overhead. The most significant value from the task breakdown is the comparison of total actual hours to total estimated hours. Team LEDmote spent 276.6 hours more than it estimated for the semester. Many of this extra spending was generated from an extended hardware design time that was predicted to end with board layout, but instead continued on through the entire semester.

7 Testing and Verification

Testing and verification was used in every aspect of the design to check that each part of the design was working and to determine the tolerances of the device.

7.1 Hardware Testing

7.1.1 MCU

The MCU testing was mostly performed using LEDs on the HPC Explorer board and monitoring the PWM outputs

7.1.2 Bluetooth

See section 8.1.1.

7.1.3 Zigbee

After confirming that a signal was being sent from one Zigbee module to another, the team began to run tests on the range to determine the actual tolerances. Table 24 shows the results.

Table 24 - Zigbee Test Results

Location	Range in meters (feet)	Obstacles	Wireless Interference
Open Air	200 – 250 (656 – 820)	None	None
Engineering Building	50 – 60 (164 – 197)	None	Wi-Fi (a,b,g)
Johnny's Cafe	20 – 25 (66 – 82)	Brick Walls	Wi-Fi (a,b,g)
Dorms	10 – 12 (33 – 39)	Concrete Walls and Wood Doors	Wi-Fi (a,b,g)
Library	10 – 12 (33 – 39)	Steel Bookshelves	Wi-Fi (a,b,g)

The office environment is a mix between the Engineering Building and the Library environments. The Engineering Building has open bays with very few walls or obstructions. It does, however, have interference from Wi-Fi. The Library environment has rows of steel bookshelves and interference from Wi-Fi. A typical office building might have steel and padded cubicles within rooms of plaster walls and may also have Wi-Fi interference. This means that lamps would have to be within 10 meters (33 feet) of each other to ensure a connected network, and with less interference, lamps could be spaced up to 50 meters (164 feet) apart.

7.1.4 Remote

Testing a piece of hardware requires small steps and checks on key points. Several important features must be verified before any software can be loaded on the system. The sequence of tests was laid out in Table 25. This was used for both the remote and lamp base PCBs.

Table 25 - Initial PCB Test Procedure

Test	Part being tested	Method	Successful Result
Power Test	Power Jack/Voltage Regulator	Touch the lead of an Oscilloscope to the hot lead on the power jack and voltage regulator	4.5V/12V is shown on the jack and 3.3V is shown on the output of the voltage regulator
Clock Test	Zigbee chip, MCU, Bluetooth chip	Touch the lead of an Oscilloscope to the clock input pins	Bluetooth = 15MHz Zigbee = 20MHz MCU = 20MHz
RF Output Test	RF Lines	Touch the lead of an Oscilloscope to the inputs of the two RF antennas	A frequency of 2.4GHz is shown on the RF lines
MCU Communication Test	MCU	Plug in ICD2 programmer	Verify that the MCU is recognized in software
Hello World	MCU	Run "Hello World" demonstration program on the MCU	Verify that the Correct output pins show a voltage
UART Test	MCU	Run UART test software on the MCU	Verify that the UART pins show the correct sequence
SPI Test	MCU	Run SPI test software on the MCU	Verify that the SPI pins show the correct sequence

The remote PCB passed all the power tests, but did not pass all the clock tests. The MCU did not have a 20MHz clock input; it was only a 2.5MHz clock signal. Also, the RF Output Test and MCU Communication Test did not pass, probably caused by the earlier failure of the Clock Test.

7.1.5 Encoder

7.1.5.1 Hook-Up

The encoder chip, MM74C922, was first placed down on the Proto-Board. Ground and V_{cc} wires were then attached to pins 10 and 20, respectively. These wires were not hooked up yet, however. A 10 uF capacitor was connected to the key-bounce mask, pin 7, in order for the chip to pull off any de-bouncing from the buttons. Another 1 uF capacitor was connected to the Oscillator Input, pin 6, which was specified to be 1/10 the size of the key-bounce capacitor. An inverter chip, MM74C04, was connected between the Data Available output, pin 13, and Output Enable, pin 15, which is an active low input. This was done so that when the chip sends out a signal, notifying that the data is ready to send, the chip also

gets activated to send out that data. If this was not done, the encoder would be constantly sending out the data to the microprocessor. Next, the 11 buttons had to be connected to inputs Y1:4 and X1:4. This was done according to the truth table and given to us from the datasheet of the encoder chip, shown in Table 26 below.

Table 26 – Encoder Chip Truth Table

	Switch	Power	White Up	White Down	Red Up	Red Down	Green Up	Green Down	Blue Up	Blue Down	Color Up	Color Down
	Inputs	Y1,X2	Y1,X3	Y1,X4	Y2,X1	Y2,X2	Y2,X3	Y2,X4	Y3,X1	Y3,X2	Y3,X3	Y3,X3
Outputs	A	1	0	1	0	1	0	1	0	1	0	1
	B	0	1	1	0	0	1	1	0	0	1	1
	C	0	0	0	1	1	1	1	0	0	0	0
	D	0	0	0	0	0	0	0	1	1	1	1

7.1.5.2 Testing

Once the encoder was thought to be hooked up correctly and checked over a few times, some simple tests were performed to ensure the correct operation of the encoder was run. Some wires were connected to output pins 16 to 19 and were then connected to an oscilloscope. A power supply was then turned on and set to 3.3 volts with a max current set just above the typical current ratings for the chip. Each button was then pushed and the outputs were monitored on 4 different channels to check the outputs according to the table. Everything was verified to be working correctly and the outputs were right around 3.3V when active.

The 3.3 V posed a problem, however. Through testing the microcontroller in another section, it was found that the inputs were active low, meaning that signals are only recognized if the inputs are pulled to ground. This was a problem since the processor would not recognize the outputs from the encoder correctly, if at all.

7.1.6 Inverter

7.1.6.1 Hook Up

To solve this problem, the outputs would have to be inverted. Since an inverter chip was already being used for the encoder chip, it was decided that the same chip could be used for the outputs. The chip included six individual inverters embedded inside, so another 8 pins were used for the outputs.

7.1.6.2 Testing

Once again the circuit had to be tested to ensure the operation of the encoder chip. The power was then turned on again, set to the right voltage and current limiting levels and then plugged into the proto-board. Once again the oscilloscopes were set up to read the four output channels and the buttons were pressed again. The outputs began as expected out and became inverted. Then a button was pressed and held down and the low levels went high and the high levels all went low. This phase also operated correctly. The button that was pressed was then released and a problem was noticed. The lines did not return to their idle state. In order to make sure that the chip was still operating, a

probe was attached to the Output Enable input, which was also being run through the inverter chip. This line was operating correctly, so we knew that the chip was still working.

It was concluded that the inputs could recognize an active high input but could not recognize an active low input. In order to correct this, pull-down resistors were attached to the inputs of the inverter chip. The circuit was powered up once again and tested the same way as above. This time everything was functioning correctly. Below, in Figure 23, is a picture that displays the circuit connections of the button array, encoder, and inverter. This will then be connected to the Remote Control Processor to test if the inputs are being decoded correctly in the software.

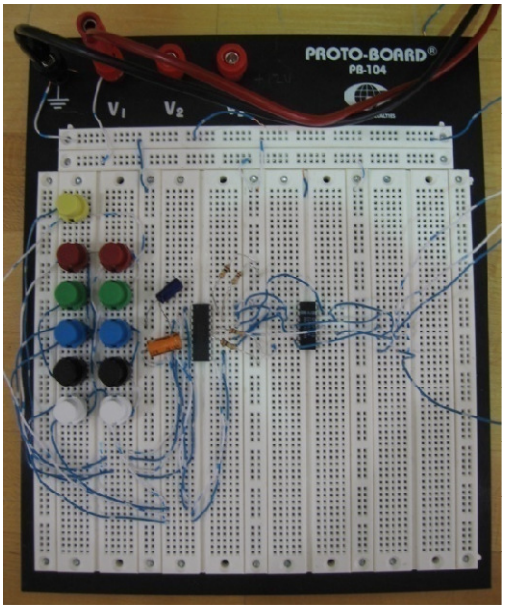

Figure 23 – Bread-boarded components of Prototype Remote Control

7.2 Software Testing

7.2.1 PC Software

The software went through extensive testing even though the final version did not have full Bluetooth functionality. Each mode was tested to be sure they would retain the values. The scheduler was tested in every recurrence scenario. Each setup option was tested along with the color panel. Everything proved to be fully functional. Through the testing process some glitches were discovered in the scheduling code that was immediately remedied.

7.2.2 PIC program

To test the programs for the processors MPLAB provides a very useful debugging tool incorporated into it. After some code had been written, the processor would be programmed normally and the program would be checked from a hardware aspect. If these tests did not work, the program would then be test using one of the debuggers inside MPLAB. The first debugger that would be used, is the programmed debug on the processor itself. In this debug mode, the user is able to step through the program and see

if it is following the correct path that it should be following. The second debugger is called MPLAB SIM, which is a debugger that does not use the processor itself, but instead MPLAB tries to simulate what the processor would be doing. Both of these debuggers were very useful in programming the processors. Another nice feature that MPLAB supports is the use of Breakpoints. These can be set anywhere in program and would pause the debugger so that you can then start stepping through the program. The last feature used in testing the PIC programs was the Watch Window. This window allowed the user to select any variable or port on the processor and see what value it is currently at.

8 Conclusion

8.1 Recommendations

8.1.1 Bluetooth

The team was able to get the Bluetooth dongle kits working together. Unfortunately given time constraints the Bluetooth was not connected to the final prototype. The microprocessor was operational until just days before the senior design night. The team feels that another couple weeks that Bluetooth would have been implemented and fully operational. The PC software was Bluetooth ready. The utilization of the Bluetooth framework library made the connection process with visual basic seamless. Unfortunately given no hardware to communicate with this PC, functionality was not implemented. In retrospect the team feels that they should have started the development kit prototype a couple weeks earlier in order to implement Bluetooth.

8.1.2 Working PCBs

The team recommends the addition of a 10MHz oscillator to clock the microprocessors on all the PCBs. This allows the processors to run at a faster rate and so overcomes the complications detailed in Section 4.3.

The team also recommends that soldering of components be done by a professional electrician or by machine so that more accurate soldering connections can be made.

8.1.3 Lamp Base Transistors

Team LEDmote only determined late in the prototype development stage of the project that an amplifying circuit of some kind would be needed. It had not been forseen that the output voltage from the processor would be insufficient to power the LEDs directly and it was not until the testing stage that this problem arose. In designing an amplifier circuit, the team chose the most readily available transistors, the VN88AFs[43], that would function effectively for the design. However, the VN88AFs were rated much higher than necessary, particularly in the area of drain-source voltage, which has a maximum value of 80V. In a production system, a lower rated and cheaper transistor would be more appropriate. One difficulty in finding an appropriate transistor was that the output voltage from the microprocessor was 3.3V. The transistors were thus required to have a gate-source voltage of about

[43] (Vishay)

3.3V. However, many transistor datasheets do not state the gate-source voltage rating for their transistor.

In production, the team has researched several possible MOSFETs that could be used to provide better amplifier efficiency. These include the Vishay Siliconix Si2312BDS[44], Fairchild FDS6570A[45], and Fairchild FDS8926A[46]. The main reason for not selecting these MOSFETs in the prototype was that all three are surface-mount parts and the prototype consisted of bread-boarded components.

8.1.4 Remote User Interface

In hindsight, the remote control user interface could be more intuitive. One recommendation is to include a symbolic labeling system with the remote control buttons to clarify which buttons control which functions. For example, the power button could have a standard power symbol added to it while the other buttons could have "+" and "-" symbols added. This would increase the costs of the remote control (See Section **Error! Reference source not found.**) but would provide clarity for the user. The team looked into purchasing decals/stickers to place on the prototype but was unable to locate any vendors able to produce stickers on a small scale prototype without excessively exceeding the budget. In an industrial setting, the remotes could be mass produced, making the addition of decals a more financially feasible option.

8.1.5 Motion or Heat Sensor

While the team determined that the addition of a motion detector to be included with the prototype would be beyond the scope of the project in the given time frame, the team does recommend that the use of motion detectors in a production design be explored. Such detectors could prove valuable in minimizing wasted energy from unnecessarily leaving lighting systems on while no person is in a room. The only foreseeable drawback to the motion detector system is that in some modern-day detector systems the lighting systems shut down if a person stays relatively motionless in a room for an extended period of time. For this reason, the team believes Innotec should explore the use of heat detectors as an alternative to motion detectors to use with the LEDmote system.

8.2 Reflections

Many lessons were learned by team LEDmote throughout the design process. These lessons involved scheduling, design steps, and documentation. Scheduling is a delicate process for the experienced; for the relatively inexperienced team LEDmote scheduling became even more of a test. Table 21 in section 6.2 display this scheduling difficulty clearly. The actual hours spent over the course of the semester over shot the estimations by 276.6 hours, a 20% over shoot. In retrospect, the team should have rearranged the design process and allowed for more design and debugging time.

In the schedule plan, hardware design was limited to the beginning of the semester. All hardware was to be completed at the beginning of the semester before any work on the software was done. This structure eventually led to the inevitable problems that occurred in the original design. A better a

[44] (Vishay)
[45] (Fairchild Semiconductor)
[46] (Fairchild Semiconductor)

strategy would have been to order development kits at the very beginning of the semester, get the software working, gain a familiar understanding of how the development kits are laid out, and then move on to design of hardware. A strategy such as this would have given the team enough time to get more of the components working and possibly a little time to order PCBs near the end of the semester.

Since hardware design time was stretched out, other aspects of the schedule suffered. Hardware debugging and software design time were shortened to accommodate the extra design time. With less time to debug the PCBs, a quick decision had to be made to abandon them and switch to development kits in order to achieve a working prototype. This chain reaction made way for the development kit prototype that the semester ended with instead of a working design laid out on PCBs.

Another problem encountered during the semester was a lack of proper documentation. Documentation of every aspect of the design process is a critical. Improper documentation caused the team to do multiple orders for parts, which in turn delayed fabrication. Improper documentation also caused more time at the end of the semester to be devoted to the report. If decisions and design strategies were recorded during the process of design, then less time would be consumed recalling this information.

8.3 Acknowledgements

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Murata Electronics

TEW

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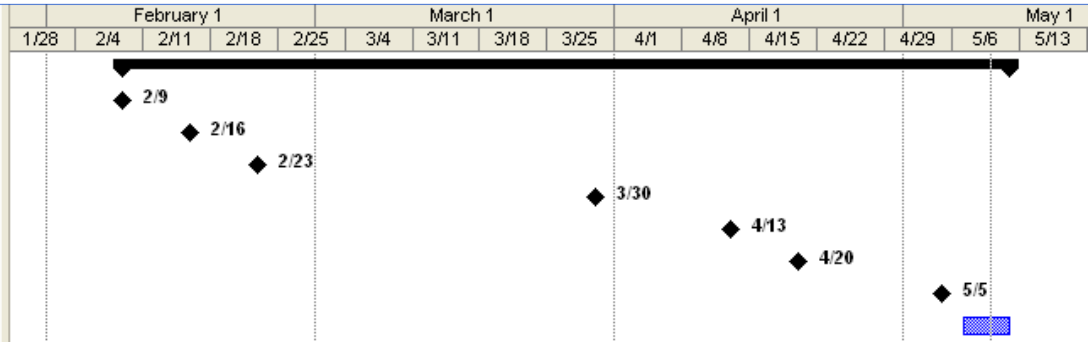
10 Appendices

10.1 Microsoft “Milestones” Project File

	Task Name	Duration	Start	Finish
1	**Milestones**	**67 days**	**Fri 2/9/07**	**Fri 5/11/07**
2	Schematic Layout	1 day	Fri 2/9/07	Fri 2/9/07
3	Circuit Board Layout	1 day	Fri 2/16/07	Fri 2/16/07
4	Order Boards	1 day	Fri 2/23/07	Fri 2/23/07
5	Working/Tested Hardware	1 day	Fri 3/30/07	Fri 3/30/07
6	Working/Tested Software	1 day	Fri 4/13/07	Fri 4/13/07
7	Working/Tested Prototype	1 day	Fri 4/20/07	Fri 4/20/07
8	Senior Design Banquet	1 day	Sat 5/5/07	Sat 5/5/07
9	Project Review by Professors	5 days	Mon 5/7/07	Fri 5/11/07



10.2 Bill of Materials

10.2.1 LED Array Bill of Materials

QTY	REFERENCE	PRODUCT NAME	DESCRIPTION	PART NUMBER	MANUFACTURER	PACKAGING	UNIT BULK PRICE	TOTAL BULK PRICE
16	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R16	Resistor	RES 442 OHM 1/4W 1% 1206 SMD	CRCW1206442RFKEA	Dale/Vishay	Tape & Reel	$0.005	$0.080
16	R45, R46, R47, R48, R49, R50, R51, R52, R53, R54, R55, R56, R57, R58, R59, R60	Resistor	RES 412 OHM 1/4W 1% 1206 SMD	CRCW1206412RFKEA	Dale/Vishay	Tape & Reel	$0.005	$0.080
8	R17, R18, R19, R20, R21, R22, R23, R24	Resistor	RES 499 OHM 1/4W 1% 1206 SMD	CRCW1206499RFKEA	Dale/Vishay	Tape & Reel	$0.005	$0.040
20	R25, R26, R27, R28, R29, R30, R31, R32, R33, R34, R35, R36, R37, R38, R39, R40, R41, R42, R43, R44	Resistor	RES 2.43 OHM 1W 1% 2512 SMD	CRCW25122R43FNEG	Dale/Vishay	Tape & Reel	$0.044	$0.880
10	LED1, LED2, LED3, LED4, LED5, LED6, LED7, LED8, LED9, LED10	Golden DRAGON	LED WHITE DIFFUSED 1WATT SMD	LW W5SG-GYHY-5K8L-Z	OSRAM	White SMD	$2.570	$25.700
8	LED11, LED12, LED13, LED14, LED15, LED16, LED17, LED18	Hyper Multi TOPLED	LED MULTI TOPLED 617NM AMB 4PLCC	LATBT66C-RS-1+ST7-35+P7Q7-35-20-R18-ZB	OSRAM	White P-LCC-4	$0.537	$4.296
1	CON1	Connector	CONN HEADER 5POS 7.92MM R/A TIN	DF22L-5P-7.92DS	Hirose Electronic Co Ltd.	Bulk	$0.480	$0.480
1	L1	Inductor	INDUCTOR THIN FILM 2.2NH 0603	L0603R2AHLTR	AVX Corporation	Tape & Reel	$0.405	$0.405

Total Component Costs For Conference Room: $31.961

Total Component Costs For Desk Lamp: $18.67

10.2.2 Remote Control Bill of Materials

	QTY	REFERENCE	PRODUCT NAME	DESCRIPTION	PART NUMBER	MANUFACTURER	UNIT BULK PRICE	TOTAL BULK PRICE
Generic Components	1	BHO	Battery Holder	Holds AA Batteries for remote	BC3AAW	MPD	$0.629	$0.629
	2	SW1,2	Black Switches	Color Brightness	D6R90 LFS	ITT Industries	$0.405	$0.810
	1	SW3	Yellow Switch	Power On/Off Switch	D6R30 LFS	ITT Industries	$0.405	$0.405
	2	SW4,5	Blue Switches	Blue Switches for Blue coloration	D6R60 LFS	ITT Industries	$0.405	$0.810
	2	SW6,7	Red Switches	Red Switches for Red coloration	D6R40 LFS	ITT Industries	$0.405	$0.810
	2	SW8,9	Green Switches	Grn Switches for Grn coloration	D6R50 LFS	ITT Industries	$0.405	$0.810
	2	SW10,11	White Switches	White Brightness	D6R00 LFS	ITT Industries	$0.405	$0.810
	1	CONN3	Connector	Conn Mod Jack 6-6 R/A PCB 50AU	555165-1	Tyco Electronics/AMP	$0.457	$0.457
	1	PIC18F6XJ1X	Microcontroller	IC PIC MCU FLASH 32KX16 64TQFP	PIC18F66J10T-I/PT	Microchip	$2.960	$2.960
	1		Enclosure	CASE STY BAT GRY 6.7 x 3.3 x 1.33	1599 ESGYBAT	Hammond Manufacturing	$4.950	$4.950
Zigbee Components	1	C44	Capacitor	CAP CER .3PF 50V COG 0402	GJM1555C1HR30BB01D	Murata	$0.022	$0.022
	4	C40, C41, C42, C43	Capacitor	CAP CER .5PF 50V C0G 0603	GRM1885C1HR50CZ01D	Murata	$0.009	$0.035
	2	C3, C4	Capacitor	CAP CER 20PF 50V 5% C0G 0603	GRM1885C1H200JA01D	Murata	$0.009	$0.018
	4	C6, C10, C11, C45	Capacitor	CAP CER 27PF 50V 5% C0G 0603	GRM1885C1H270JA01D	Murata	$0.009	$0.035
	1	C13	Capacitor	CAP CER 47PF 50V 5% C0G 0603	GRM1665C1H470JA01D	Murata	$0.009	$0.009
	2	C8, C12	Capacitor	CAP CER 10000PF 16V 10% X7R 0603	GRM188R71C103KA01D	Murata	$0.007	$0.014
	2	C14, C46	Capacitor	CAP CER .1UF 16V Y5V 0603	GRM188F51C104ZA01D	Murata	$0.007	$0.014
	1	C5	Capacitor	CAP CER 180PF 50V 5% C0G 0603	GRM1885C1H181JA01D	Murata	$0.013	$0.013
	1	C7	Capacitor	CAP CER 2.2UF 10V Y5V 0603	GRM188F51A225ZE01D	Murata	$0.021	$0.021
	2	C47, C48	Capacitor	CAP CERAMIC 7PF 50V C0G 0603	GQM1885C1H7R0CB01D	Murata	$0.241	$0.482
	1	OSC1	Crystal Oscilator	CRYSTAL 20.000MHZ 18PF FUND SMD	ABM8-20.000MHZ-B2-T	Abracon Corporation	$1.131	$1.131
	1	MRF24J40	Zigbee Chip	IC TXRX IEEE/ZIGBEE 2.4GHZ 40QFN	MRF24J40-I/ML	Microchip Technology	$3.590	$3.590
	2	R1	Resistor	RES 0.0 OHM 1/10W 5% SMD	CRCW06030000Z0TA	Vishay/Dale	$0.003	$0.006
	1	R2	Resistor	RES 10K OHM 1/10W 5% 0603 SMD	CRCW060310K0JNEA	Vishay/Dale	$0.003	$0.003
	1	L6	Inductor	INDUCTOR MULTILAYER 4.7NH 0603	MLG1608B4N7S	TDK Corporation	$0.043	$0.043
	1	L5	Inductor	INDUCTOR MULTILAYER 5.6NH 0603	MLG1608B5N6D	TDK Corporation	$0.043	$0.043
	2	L2, L4	Inductor	INDUCTOR MULTILAYER 10NH 0603	MLG1608B10NJ	TDK Corporation	$0.043	$0.085
	1	OSC2	Oscillator	OSC 32.768KHZ 5+/-23PPM SMD	SG-3030JC 32.7680KB3	Epson Electronics	$1.48632	$1.486
Processor	1	CONN3	Connector	Conn Mod Jack 6-6 R/A PCB 50AU	555165-1	Tyco Electronics/AMP	$0.457	$0.457
	1	IC1	Voltage Regulator	IC STP-DN SW VOLT-REG 3.3V 16DIP	TL2575-33IN	Texas Instruments	$0.750	$0.750
	1	C1	Capacitor	CAP ELECT 100UF 16V VS SMD	ECE-V1CA101P	Panasonic - ECG	$0.106	$0.106
	1	C2	Capacitor	CAP ELECT 330UF 6.3V VS SMD	ECE-V0JA331P	Panasonic - ECG	$0.106	$0.106
	1	C9	Capacitor	CAP CER 10UF 6.3V X5R 0603	GRM188R60J106ME57D	Murata	$0.120	$0.120
	1	D1	Diode	DIODE SCHOTTKY 40V 1A SOD123	1N5819HW-7-F	Diodes Inc	$0.234	$0.234
	1	L1	Inductor	INDUCTOR MULTILAYER 330UH 1210	NLV32T-331J-PF	TDK Corporation	$0.077	$0.077
						Total Component Costs:		$22.352

10.2.3 Base Bill of Materials (Slave)

	QTY	REFERENCE	PRODUCT DESC.	DESCRIPTION	PART NUMBER	MANUFACTURER	UNIT BULK PRICE	TOTAL BULK PRICE
Processor & Power	1	IC1	Voltage Regulator	IC STP-DN SW VOLT-REG 3.3V 16DIP	TL2575-33IN	Texas Instruments	$0.750	$0.750
	1		Pow er Supply	Trans Table Top 12VDC 4A E-Star	ETS120400UTC-P5P-SZ	CUI Inc.	$16.996	$16.996
	1	CONN1	Connector	Conn Pow er Jack 2.1X5.5MM Hi Cur	PJ-002AH-SMT	CUI Inc.	$0.360	$0.360
	1	CONN2	Connector	CONN HEADER 5POS 7.92MM R/A TIN	DF22L-5P-7.92DS	Hirose Electronic Co Ltd.	$0.480	$0.480
	1	CONN3	Connector	Conn Mod Jack 6-6 R/A PCB 50AU	555165-1	Tyco Electronics/AMP	$0.457	$0.457
	1	T1	Transistor	MOSFET N-CHAN 20V 3A SSOT3	FDN339AN	Fairchild Semiconductor	$0.175	$0.175
	3	T2, T3, T4	Transistor	MOSFET N-CH 100V 0.4A SOT-223	FDT461N	Fairchild Semiconductor	$0.273	$0.819
	1	MICROCHIP	Microcontroller	IC PIC MCU FLASH 32KX16 64TQFP	PIC18F66J10T-I/PT	Microchip	$2.960	$2.960
	1	C1	Capacitor	CAP ELECT 100UF 16V VS SMD	ECE-V1CA101P	Panasonic - ECG	$0.106	$0.106
	1	C2	Capacitor	CAP ELECT 330UF 6.3V VS SMD	ECE-V0JA331P	Panasonic - ECG	$0.106	$0.106
	1	C9	Capacitor	CAP CER 10UF 6.3V X5R 0603	GRM188R60J106ME57D	Murata	$0.120	$0.120
	1	D1	Diode	DIODE SCHOTTKY 40V 1A SOD123	1N5819HW-7-F	Diodes Inc	$0.234	$0.234
	1	L1	Inductor	INDUCTOR MULTILAYER 330UH 1210	NLV32T-331J-PF	TDK Corporation	$0.077	$0.077
Zigbee	1	C44	Capacitor	CAP CER .3PF 50V COG 0402	GJM1555C1HR30BB01D	Murata	$0.022	$0.022
	4	C40, C41, C42, C43	Capacitor	CAP CER .5PF 50V C0G 0603	GRM1885C1HR50CZ01D	Murata	$0.009	$0.035
	2	C3, C4	Capacitor	CAP CER 20PF 50V 5% C0G 0603	GRM1885C1H200JA01D	Murata	$0.009	$0.018
	4	C6, C10, C11, C45	Capacitor	CAP CER 27PF 50V 5% C0G 0603	GRM1885C1H270JA01D	Murata	$0.009	$0.035
	1	C13	Capacitor	CAP CER 47PF 50V 5% C0G 0603	GRM1665C1H470JA01D	Murata	$0.009	$0.009
	2	C8, C12	Capacitor	CAP CER 10000PF 16V 10% X7R 0603	GRM188R71C103KA01D	Murata	$0.007	$0.014
	2	C14, C46	Capacitor	CAP CER .1UF 16V Y5V 0603	GRM188F51C104ZA01D	Murata	$0.007	$0.014
	1	C5	Capacitor	CAP CER 180PF 50V 5% C0G 0603	GRM1885C1H181JA01D	Murata	$0.013	$0.013
	1	C7	Capacitor	CAP CER 2.2UF 10V Y5V 0603	GRM188F51A225ZE01D	Murata	$0.021	$0.021
	2	C47, C48	Capacitor	CAP CERAMIC 7PF 50V C0G 0603	GQM1885C1H7R0CB01D	Murata	$0.214	$0.428
	1	OSC1	Crystal Oscilator	CRYSTAL 20.000MHZ 18PF FUND SMD	ABM8-20.000MHZ-B2-T	Abracon Corporation	$1.131	$1.131
	1	MRF24J40	Zigbee Chip	IC TXRX IEEE/ZIGBEE 2.4GHZ 40QFN	MRF24J40-I/ML	Microchip Technology	$3.590	$3.590
	2	R1	Resistor	RES 0.0 OHM 1/10W 5% SMD	CRCW06030000Z0TA	Vishay/Dale	$0.003	$0.006
	1	R2	Resistor	RES 10K OHM 1/10W 5% 0603 SMD	CRCW060310K0JNEA	Vishay/Dale	$0.003	$0.003
	1	L6	Inductor	INDUCTOR MULTILAYER 4.7NH 0603	MLG1608B4N7S	TDK Corporation	$0.043	$0.043
	1	L5	Inductor	INDUCTOR MULTILAYER 5.6NH 0603	MLG1608B5N6D	TDK Corporation	$0.043	$0.043
	2	L2, L4	Inductor	INDUCTOR MULTILAYER 10NH 0603	MLG1608B10NJ	TDK Corporation	$0.043	$0.085
	1	OSC2	Oscillator	OSC 32.768KHZ 5+/-23PPM SMD	SG-3030JC 32.7680KB3	Epson Electronics	$1.48632	$1.486

Total Slave Component Costs: **$30.637**

10.2.4 Base Bill Of Materials (Master Components)

	QTY	REFERENCE	PRODUCT DESC.	DESCRIPTION	PART NUMBER	MANUFACTURER	UNIT BULK PRICE	TOTAL BULK PRICE
Bluetooth	1	OSC4	Crystal Oscillator	13.000MHz	TAS-4025A	TEW	$0.48000	$0.480
	5	C29, C15, C17, C23, C27	Capacitor	CAP CER 10000PF 50V 10% X7R 0603	GRM188R71H103KA01D	MuRata	$0.00882	$0.044
	1	C16	Capacitor	CAP TANT 1.0UF 10V 10% 0603 SMD	TACL105K010XTA	AVX Corporation	$1.04000	$1.040
	1	C18	Capacitor	CAP TANT 2.2UF 16V 20% 0603 SMD	TACL225M016XTA	AVX Corporation	$1.04000	$1.040
	1	C19	Capacitor	CAP CER 100PF 50V 5% C0G 0603	GQM1885C1H101JB01D	MuRata	$0.27800	$0.278
	4	C20, C24, C25, C26	Capacitor	CAP CER .1UF 16V 10% X7R 0603	GRM188R71C104KA01D	MuRata	$0.01476	$0.059
	2	C21, C22	Capacitor	CAP CER 4.7PF 50V C0G 0603	GRM1885C1H4R7CZ01D	MuRata	$0.01134	$0.023
	1	C28	Capacitor	CAP CER 2.2UF 10V Y5V 0603	GRM188F51A225ZE01D	MuRata	$0.02754	$0.028
	2	C30, C31	Capacitor	CAP CER 12PF 50V 5% C0G 0603	GRM1885C1H120JA01D	MuRata	$0.01134	$0.023
	1	C32	Capacitor	CAP CERAMIC 8.2PF 50V C0G 0603	GQM1885C1H8R2CB01D	MuRata	$0.21400	$0.214
	1	C33	Capacitor	CAP CER 220PF 50V 5% C0G 0603	GRM1885C1H221JA01D	MuRata	$0.01656	$0.017
	1	C34	Capacitor	CAP CER 2200PF 50V 10% X7R 0603	GRM188R71H222KA01D	MuRata	$0.00666	$0.007
	1	C35	Capacitor	CAP CER 39PF 50V 5% C0G 0603	GRM1885C1H390JA01D	MuRata	$0.01134	$0.011
	1	C36	Capacitor	CAP CER .1UF 16V Y5V 0603	GRM188F51C104ZA01D	MuRata	$0.00882	$0.009
	2	C37, C38	Capacitor	CAP CERAMIC 7PF 50V C0G 0603	GQM1885C1H7R0CB01D	MuRata	$0.21400	$0.428
	1	C39	Capacitor	CAP CER 1000PF 50V 10% X7R 0603	GRM188R71H102KA01D	MuRata	$0.00936	$0.009
	1	R4	Resistor	RES 1.00K OHM 1/10W 1% 0603 SMD	CRCW06031K00FKEA	Vishay/Dale	$0.00400	$0.004
	1	R5	Resistor	RES 523 OHM 1/10W 1% 0603 SMD	RC0603FR-07523RL	Yageo Co	$0.00480	$0.005
	1	R6	Resistor	RES 130 OHM 1/10W 1% 0603 SMD	RC0603FR-07130RL	Yageo Co	$0.00480	$0.005
	5	R3, R7, R8, R13, R14	Resistor	RES 1.00K OHM 1/4W 1% 0603 SMD	CRCW06031K00FKEA	Vishay/Dale	$0.00700	$0.035
	1	R9	Resistor	RES 100K OHM 1/10W 1% 0603 SMD	CRCW0603100KF5EA	Vishay/Dale	$0.00400	$0.004
	1	R10	Resistor	RES 0.0 OHM 1/10W 5% 0603 SMD	RC0603JR-070RL	Yageo Co	$0.00330	$0.003
	1	R11	Resistor	RES 3.30K OHM 1/10W 1% 0603 SMD	CRCW06033K30FKEA	Vishay/Dale	$0.00400	$0.004
	1	R12, R16	Resistor	RES 10.0K OHM 1/10W 1% 0603 SMD	CRCW060310K0FKEA	Vishay/Dale	$0.00400	$0.004
	2	L3, L7	Inductor	INDUCTOR 3.9NH 450MA 0603	LQG18HN3N9S00D	MuRata	$0.06125	$0.123
	1	LED1	LED	LED 1.5V BLUE WTR CLR 1210 SMD	SML-DSP1210USBC-TR	Lumex Opto	$1.22840	$1.228
	1	LED2	LED	LED 1.5V RED WTR CLR 1210 SMD	SML-DSP1210SIC-TR	Lumex Opto	$1.01260	$1.013
	1	IC2	Voltage Regulator	IC REG ULTRA LDO 150MA SOT-23-5	LP3985IM5-2.8TR-NOPB	National Semiconductor	$0.32200	$0.322
	1	IC3	EEPROM	IC SRL EE 64K 1.8V 8TSSOP	AT24C64A-10TE-1.8	Atmel	$0.71000	$0.710
	1	OSC3	Oscillator	OSC 32.768KHZ 5+/-23PPM SMD	SG-3030JC 32.7680KB3	Epson Electronics	$1.48632	$1.486
	1	U9	Bluetooth Module	MODULE BLUETOOTH SRL PORT 60BGA	LMX9830SMX	National Semiconductor	$9.78075	$9.781

Total Master Component Costs: $49.072

10.3 LED Array Worst Case Component Analysis

A. COMPONENT DEFINITIONS, ASSUMPTIONS, AND REQUIREMENTS

1. VOLTAGES

i. SOURCE

$V_{Source} := 12V$ $V_{SourceMax} := 12.6V$ $V_{SourceMin} := 11.4V$

ii. REGULATED

$V_{Regulated} := 3V$ $V_{RegulatedMax} := 3.2V$ $V_{RegulatedMin} := 2.8V$

2. LED

i. FORWARD VOLTAGE

$V_{FWhite} := 3.8V$ $V_{FWhiteMax} := 4.1V$ $V_{FWhiteMin} := 3.1V$

$V_{FRed} := 2V$ $V_{FRedMax} := 2.4V$ $V_{FRedMin} := 1.83V$

$V_{FGreen} := 3.2V$ $V_{FGreenMax} := 3.9V$ $V_{FGreenMin} := 3.0V$

$V_{FBlue} := 3.8V$ $V_{FBlueMax} := 4.1V$ $V_{FBlueMin} := 3.0V$

ii. MIN - MAX CURRENT AT 80% DUTY CYCLE

$I_{FWhite} := 450mA$ $I_{FWhiteMax} := 700mA$ $I_{FWhiteMin} := 100mA$

$I_{FRed} := 20mA$ $I_{FRedMax} := 35mA$

$I_{FGreen} := 20mA$ $I_{FGreenMax} := 25mA$

$I_{FBlue} := 20mA$ $I_{FBlueMax} := 25mA$

iii. MAX P CONSUMPTION

$MaxP_{LEDWhite} := 2.3W$

$MaxP_{LEDRed} := 80mW$

$MaxP_{LEDGreen} := 85mW$

$MaxP_{LEDBlue} := 85mW$

iiii. MAX JUNCTION TEMPERATURE

$Tj_{White} := 125C$

$Tj_{Red} := 125C$

$Tj_{Green} := 125C$

$Tj_{Blue} := 110C$

3. TRANSISTORS

i. RDS(ON)

$Rdson_{T1} := 1.2 \cdot \Omega$

$Rdson_{T2..4} := 1.5 \cdot \Omega$

ii. VGS MAX - MIN

$VGS_{T1} := .85V$ $V_{GSmax.T1} := 1.5V$ $V_{GSmin.T1} := .4V$

$V_{GSmax.T2..4} := 2V$ $V_{GSmin.T2..4} := .8V$

iii. DRAIN CURRENT MAX

$Id_{T1} := 3A$

$Id_{T2..4} := 400mA$

iv. MAX JUNCTION TEMPERATURE

$Tj_{T1} := 150C$

$Tj_{T2..4} := 150C$

4. RESISTORS

i. OHMS

$R_{1..8} := 442 \cdot \Omega$

$R_{9..16} := 412 \cdot \Omega$

$R_{17..24} := 499 \cdot \Omega$

$R_{25..44} := 2.43 \cdot \Omega$

ii. TOLERANCE

$R_{1..8Tolerance} := 1\%$

$R_{9..16Tolerance} := 1\%$

$R_{17..24Tolerance} := 1\%$

$R_{25..44Tolerance} := 1\%$

iii. P

$PRating_{R1..8} := .25W$

$PRating_{R9..16} := .25W$

$PRating_{R17..24} := .25W$

$PRating_{R25..44} := 1W$

5. MAX DUTY CYCLE

$MaxDutyCycle_{White} := 75\%$

$MaxDutyCycle_{Red} := 75\%$

$MaxDutyCycle_{Green} := 75\%$

$MaxDutyCycle_{Blue} := 75\%$

B. WHITE LED CIRCUIT CALCULATIONS

1. RESISTORS

i. OHM

$$R_{25..44Calc} := \frac{V_{Source} - V_{FWhite} \cdot 2}{I_{FWhite} \cdot 4} \qquad R_{25..44Calc} = 2.444\,\Omega$$

$$R_{25..44Max} := R_{25..44}\left(1 + R_{25..44Tolerance}\right) \qquad R_{25..44Max} = 2.454\,\Omega$$

$$R_{25..44Min} := R_{25..44}\left(1 - R_{25..44Tolerance}\right) \qquad R_{25..44Min} = 2.406\,\Omega$$

ii. CURRENT

$$MaxCurrent_{R25..44} := \frac{V_{SourceMax} - V_{FWhiteMin} \cdot 2}{\left[R_{25..44}\left(1 - R_{25..44Tolerance}\right)\right] \cdot 4} \cdot MaxDutyCycle_{White}$$

$$MaxCurrent_{R25..44} = 0.499A$$

iii. POWER

$$MaxP_{R25..44} := R_{25..44} MaxCurrent_{R25..44}^{2} \qquad MaxP_{R25..44} = 0.605\,W$$

iiii. MARGINS

$$PMargin_{R25..44} := \frac{PRating_{R25..44} - MaxP_{R25..44}}{PRating_{R25..44}}$$

$$PMargin_{R25..44} = 39.538\%$$

2. LED

i. CURRENT & MARGIN

$$MaxCurrent_{LEDWhite} := \frac{V_{SourceMax} - V_{FWhiteMin} \cdot 2}{\left[R_{25..44}\left(1 - R_{25..44Tolerance}\right)\right] \cdot 4}$$

$$MaxCurrent_{LEDWhite} = 665.087mA$$

$$CurrentMargin_{LEDWhite} := \frac{I_{FWhiteMax} - MaxCurrent_{LEDWhite}}{I_{FWhiteMax}}$$

$$CurrentMargin_{LEDWhite} = 4.988\%$$

ii. POWER AND MARGIN

$$P_{LEDWhite} := V_{FWhite} \cdot I_{FWhite}$$

$$P_{LEDWhite} = 1.71\,W$$

$$MaxCalcP_{LEDWhite} := V_{FWhiteMin} \cdot MaxCurrent_{LEDWhite}$$

$$MaxCalcP_{LEDWhite} = 2.062\,W$$

$$PMargin_{LEDWhite} := \frac{MaxP_{LEDWhite} - MaxCalcP_{LEDWhite}}{MaxP_{LEDWhite}}$$

$$PMargin_{LEDWhite} = 10.358\%$$

3. TRANSISTOR

i. CURRENT AND MARGIN

$$MaxCurrent_{T1} := \frac{V_{SourceMax} - V_{FWhiteMin} \cdot 2}{\left[R_{25..44}\left(1 - R_{25..44Tolerance}\right)\right] \cdot 4} \cdot MaxDutyCycle_{White} \cdot 5$$

$$MaxCurrent_{T1} = 2.494A$$

$$CurrentMargin_{T1} := \frac{Id_{T1} - MaxCurrent_{T1}}{Id_{T1}}$$

$$CurrentMargin_{T1} = 16.864\%$$

C. GREEN LED CIRCUIT CALCULATIONS

1. RESISTORS

i. OHM

$$R_{1..8Calc} := \frac{V_{Source} - V_{FGreen}}{I_{FGreen}} \qquad R_{1..8Calc} = 440\,\Omega$$

$$R_{1..8Max} := R_{1..8}\left(1 + R_{1..8Tolerance}\right) \qquad R_{1..8Max} = 446.42\,\Omega$$

$$R_{1..8Min} := R_{1..8}\left(1 - R_{1..8Tolerance}\right) \qquad R_{1..8Min} = 437.58\,\Omega$$

ii. CURRENT

$$MaxCurrent_{R1..8} := \frac{V_{SourceMax} - V_{FGreenMin}}{R_{1..8}} \cdot MaxDutyCycle_{Green}$$

$$MaxCurrent_{R1..8} = 16.29mA$$

iii. POWER

$$MaxP_{R1..8} := R_{1..8} \cdot MaxCurrent_{R1..8}^{2} \qquad MaxP_{R1..8} = 0.117W$$

iiii. MARGINS

$$PMargin_{R1..8} := \frac{PRating_{R1..8} - MaxP_{R1..8}}{PRating_{R1..8}}$$

$$PMargin_{R1..8} = 53.086\%$$

2. LED

i. CURRENT & MARGIN

$$MaxCurrent_{LEDGreen} := \frac{V_{SourceMax} - V_{FGreenMin}}{R_{1..8}}$$

$$MaxCurrent_{LEDGreen} = 21.719mA$$

$$CurrentMargin_{LEDGreen} := \frac{I_{FGreenMax} - MaxCurrent_{LEDGreen}}{I_{FGreenMax}}$$

$$\text{CurrentMargin}_{LEDGreen} = 13.122\%$$

ii. POWER AND MARGIN

$$P_{LEDGreen} := V_{FGreen} \cdot I_{FGreen}$$

$$P_{LEDGreen} = 64\,\text{mW}$$

$$\text{MaxCalcP}_{LEDGreen} := V_{FGreenMin} \cdot \text{MaxCurrent}_{LEDGreen}$$

$$\text{MaxCalcP}_{LEDGreen} = 65.158\text{mW}$$

$$\text{PMargin}_{LEDGreen} := \frac{\text{MaxP}_{LEDGreen} - \text{MaxCalcP}_{LEDGreen}}{\text{MaxP}_{LEDGreen}}$$

$$\text{PMargin}_{LEDGreen} = 23.343\%$$

3. TRANSISTOR

i. CURRENT AND MARGIN

$$\text{MaxCurrent}_{T2} := \frac{V_{SourceMax} - V_{FGreenMin}}{R_{1..8}} \cdot \text{MaxDutyCycle}_{Green} \cdot 8$$

$$\text{MaxCurrent}_{T2} = 130.317\text{mA}$$

$$\text{CurrentMargin}_{T2} := \frac{\text{Id}_{T2..4} - \text{MaxCurrent}_{T2}}{\text{Id}_{T2..4}}$$

$$\text{CurrentMargin}_{T2} = 67.421\%$$

D. BIUE LED CIRCUIT CALCULATIONS

1. RESISTORS

i. OHM

$$R_{9..16Calc} := \frac{V_{Source} - V_{FBlue}}{I_{FBlue}} \qquad R_{9..16Calc} = 410\,\Omega$$

$$R_{9..16Max} := R_{9..16}\left(1 + R_{9..16Tolerance}\right) \qquad R_{9..16Max} = 416.12\,\Omega$$

$$R_{9..16Min} := R_{9..16}\left(1 - R_{9..16Tolerance}\right) \qquad R_{9..16Min} = 407.88\,\Omega$$

ii. CURRENT

$$\text{MaxCurrent}_{R9..16} := \frac{V_{SourceMax} - V_{FBlueMin}}{R_{9..16}} \cdot \text{MaxDutyCycle}_{Blue}$$

$$\text{MaxCurrent}_{R9..16} = 17.476\text{mA}$$

iii. POWER

$$\text{MaxP}_{R9..16} := R_{9..16} \cdot \text{MaxCurrent}_{R9..16}^{2} \qquad \text{MaxP}_{R9..16} = 0.126\,\text{W}$$

iiii. MARGINS

$$PMargin_{R9..16} := \frac{PRating_{R9..16} - MaxP_{R9..16}}{PRating_{R9..16}}$$

$$PMargin_{R9..16} = 49.67\%$$

2. LED

i. CURRENT & MARGIN

$$MaxCurrent_{LEDBlue} := \frac{V_{SourceMax} - V_{FBlueMin}}{R_{9..16}}$$

$$MaxCurrent_{LEDBlue} = 23.301mA$$

$$CurrentMargin_{LEDBlue} := \frac{I_{FBlueMax} - MaxCurrent_{LEDBlue}}{I_{FBlueMax}}$$

$$CurrentMargin_{LEDBlue} = 6.796\%$$

ii. POWER AND MARGIN

$$P_{LEDBlue} := V_{FBlue} \cdot I_{FBlue}$$

$$P_{LEDBlue} = 76mW$$

$$MaxCalcP_{LEDBlue} := V_{FBlueMin} \cdot MaxCurrent_{LEDBlue}$$

$$MaxCalcP_{LEDBlue} = 69.903mW$$

$$PMargin_{LEDBlue} := \frac{MaxP_{LEDBlue} - MaxCalcP_{LEDBlue}}{MaxP_{LEDBlue}}$$

$$PMargin_{LEDBlue} = 17.761\%$$

3. TRANSISTOR

i. CURRENT AND MARGIN

$$MaxCurrent_{T3} := \frac{V_{SourceMax} - V_{FBlueMin}}{R_{9..16}} \cdot MaxDutyCycle_{Blue} \cdot 8$$

$$MaxCurrent_{T3} = 139.806mA$$

$$CurrentMargin_{T3} := \frac{Id_{T2..4} - MaxCurrent_{T3}}{Id_{T2..4}}$$

$$CurrentMargin_{T3} = 65.049\%$$

E. RED LED CIRCUIT CALCULATIONS

1. RESISTORS

i. OHM

$$R_{17..24Calc} := \frac{V_{Source} - V_{FRed}}{I_{FRed}} \qquad R_{17..24Calc} = 500\,\Omega$$

$R_{17..24Max} := R_{17..24}\left(1 + R_{17..24Tolerance}\right)$ $R_{17..24Max} = 503.99\,\Omega$

$R_{17..24Min} := R_{17..24}\left(1 - R_{17..24Tolerance}\right)$ $R_{17..24Min} = 494.01\,\Omega$

ii. CURRENT

$$MaxCurrent_{R17..24} := \frac{V_{SourceMax} - V_{FRedMin}}{R_{17..24}} \cdot MaxDutyCycle_{Red}$$

$MaxCurrent_{R17..24} = 16.187\text{mA}$

iii. POWER

$MaxP_{R17..24} := R_{17..24} MaxCurrent_{R17..24}^{2}$ $MaxP_{R17..24} = 0.131\,\text{W}$

iiii. MARGINS

$$PMargin_{R17..24} := \frac{PRating_{R17..24} - MaxP_{R17..24}}{PRating_{R17..24}}$$

$PMargin_{R17..24} = 47.699\%$

2. LED

i. CURRENT & MARGIN

$$MaxCurrent_{LEDRed} := \frac{V_{SourceMax} - V_{FRedMin}}{R_{17..24}}$$

$MaxCurrent_{LEDRed} = 21.583\text{mA}$

$$CurrentMargin_{LEDRed} := \frac{I_{FRedMax} - MaxCurrent_{LEDRed}}{I_{FRedMax}}$$

$CurrentMargin_{LEDRed} = 38.334\%$

ii. POWER AND MARGIN

$P_{LEDRed} := V_{FRed} \cdot I_{FRed}$

$P_{LEDRed} = 40\,\text{mW}$

$MaxCalcP_{LEDRed} := V_{FRedMin} \cdot MaxCurrent_{LEDRed}$

$MaxCalcP_{LEDRed} = 39.497\text{mW}$

$$PMargin_{LEDRed} := \frac{MaxP_{LEDRed} - MaxCalcP_{LEDRed}}{MaxP_{LEDRed}}$$

$PMargin_{LEDRed} = 50.629\%$

3. TRANSISTOR

i. CURRENT AND MARGIN

$$MaxCurrent_{T4} := \frac{V_{SourceMax} - V_{FRedMin}}{R_{17..24}} \cdot MaxDutyCycle_{Red} \cdot 8$$

$$MaxCurrent_{T4} = 129.499mA$$

$$CurrentMargin_{T4} := \frac{Id_{T2..4} - MaxCurrent_{T4}}{Id_{T2..4}}$$

$$CurrentMargin_{T4} = 67.625\%$$

10.4 PC Software Design & Code

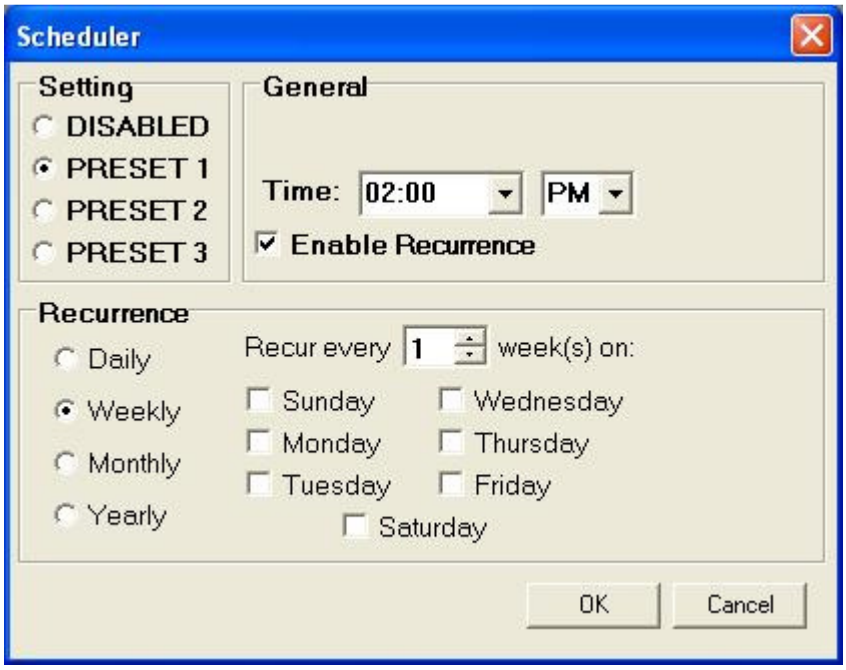
10.4.1 Credit Screen

```
Imports System
Imports System.IO

Public Class CREDITS
    Inherits System.Windows.Forms.Form

    'Run Credits and Setup

    Private Sub TimerElapsed(ByVal sender As System.Object, ByVal e As
System.Timers.ElapsedEventArgs) Handles Timer.Elapsed
        Call Load_Criteria()
        Status_Field.Text = "SEARCHING FOR MASTER LAMP ... "
        Call Master_Lamp_Search()
        Status_Field.Text = "CHECKING ENVIRONMENT CRITERIA ... "
        Call Check_Criteria()
        Status_Field.Text = "CREATING USER INTERFACE ... "
        Call Create_User_Interface()
    End Sub

    ' Load Previous Setup Criteria
    Private Sub Load_Criteria()
        Dim i, x, y As Integer
        ' Create an instance of StreamReader to read from a file.
        Dim sr As StreamReader = New StreamReader(System.AppDomain.CurrentDomain.BaseDirectory &
"Data.txt")
        Dim readcontents, textdelimiter As String
        ' Read and display the lines from the file until the end
        ' of the file is reached.
        readcontents = sr.ReadToEnd()
```

```
    textdelimiter = "#"
    Dim splitout = Split(readcontents, textdelimiter)
    sr.Close()
    UserName = splitout(0)
    Preset1Name = splitout(1)
    Preset2Name = splitout(2)
    Preset3Name = splitout(3)
    MasterLampName = splitout(4)
    For i = 5 To 103
        For x = 0 To 8
            For y = 0 To 10
                Preset1Array(x, y) = splitout(i)
                i = i + 1
            Next
            y = 0
        Next
        x = 0
    Next
    For i = 104 To 202
        For x = 0 To 8
            For y = 0 To 10
                Preset2Array(x, y) = splitout(i)
                i = i + 1
            Next
            y = 0
        Next
        x = 0
    Next
    For i = 203 To 301
        For x = 0 To 8
            For y = 0 To 10
                Preset3Array(x, y) = splitout(i)
                i = i + 1
            Next
            y = 0
        Next
        x = 0
    Next
End Sub

'Search For Master Lamp and retrieve individual Lamp Info
Private Sub Master_Lamp_Search()
    Dim i As Integer
    NumberOfLamps = 7
    For i = 0 To 8
        'Current White Intensity on Each Lamp
        CurrentArray(i, 1) = 0
        'Current Color Intensity on Each Lamp
        CurrentArray(i, 2) = 0
        'Current Red Intensity on Each Lamp
        CurrentArray(i, 3) = 0
        'Current Green Intensity on Each Lamp
        CurrentArray(i, 4) = 0
        'Current Blue Intensity on Each Lamp
        CurrentArray(i, 5) = 0
        CurrentArray(i, 6) = False
        CurrentArray(i, 7) = False
        CurrentArray(i, 8) = False
        CurrentArray(i, 9) = False
        CurrentArray(i, 10) = False
    Next
End Sub

'Save New Master Lamp Criteria
Private Sub Check_Criteria()

End Sub

'Map all variables to MAIN and Load the MAIN Screen
Private Sub Create_User_Interface()
    LEDmoteControl.Show()
```

```
        LEDmoteControl.Setup_Screne()
        Me.Hide()
    End Sub

End Class
```

10.4.2 Schedule Screen

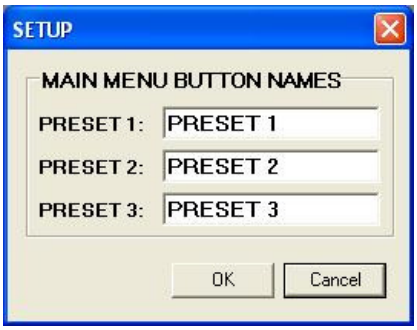



```
Imports System.Windows.Forms

Public Class Schedule
    Private Sub Form_Load()
        MsgBox("Test")
    End Sub
    Private Sub OK_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles OK_Button.Click
        Me.DialogResult = System.Windows.Forms.DialogResult.OK
        Me.Close()
    End Sub

    Private Sub Cancel_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Cancel_Button.Click
        Me.DialogResult = System.Windows.Forms.DialogResult.Cancel
        Me.Close()
    End Sub

    Private Sub Disabled_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Disabled.CheckedChanged
        If Disabled.Checked = True Then
            Me.GeneralGroup.Visible = False
            Me.RecurrenceGroup.Visible = False
        Else
            Me.GeneralGroup.Visible = True
        End If
    End Sub

    Private Sub Preset1_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Preset1.CheckedChanged
        If Preset1.Checked = True Then
            Me.GeneralGroup.Visible = True
            Me.RecurrenceEnabled.Checked = False
        Else
```

```
            Me.GeneralGroup.Visible = False
        End If
    End Sub

    Private Sub Preset2_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Preset2.CheckedChanged
        If Preset2.Checked = True Then
            Me.GeneralGroup.Visible = True
            Me.RecurrenceEnabled.Checked = False
        Else
            Me.GeneralGroup.Visible = False
        End If
    End Sub

    Private Sub Preset3_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Preset3.CheckedChanged
        If Preset3.Checked = True Then
            Me.GeneralGroup.Visible = True
            Me.RecurrenceEnabled.Checked = False
        Else
            Me.GeneralGroup.Visible = False
        End If
    End Sub

    Private Sub RecurrenceEnabled_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles RecurrenceEnabled.CheckedChanged
        If RecurrenceEnabled.Checked = True Then
            Me.RecurrenceGroup.Visible = True
            Me.Daily.Checked = True
            Me.GroupMonthly.Visible = False
            Me.GroupWeekly.Visible = False
            Me.GroupYearly.Visible = False
            Me.Date1.Visible = False
            Me.lblDate.Visible = False
        Else
            Me.RecurrenceGroup.Visible = False
            Me.Date1.Visible = True
            Me.lblDate.Visible = True
        End If
    End Sub

    Private Sub Daily_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Daily.CheckedChanged
        If Daily.Checked = True Then
            Me.GroupMonthly.Visible = False
            Me.GroupWeekly.Visible = False
            Me.GroupYearly.Visible = False
        End If
    End Sub

    Private Sub Weekly_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Weekly.CheckedChanged
        If Weekly.Checked = True Then
            Me.GroupMonthly.Visible = False
            Me.GroupWeekly.Visible = True
            Me.GroupYearly.Visible = False
        End If
    End Sub

    Private Sub Monthly_CheckedChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Monthly.CheckedChanged
        If Monthly.Checked = True Then
            Me.GroupMonthly.Visible = True
            Me.GroupWeekly.Visible = False
            Me.GroupYearly.Visible = False
        End If
    End Sub

    Private Sub Yearly_CheckedChanged(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Yearly.CheckedChanged
        If Yearly.Checked = True Then
```

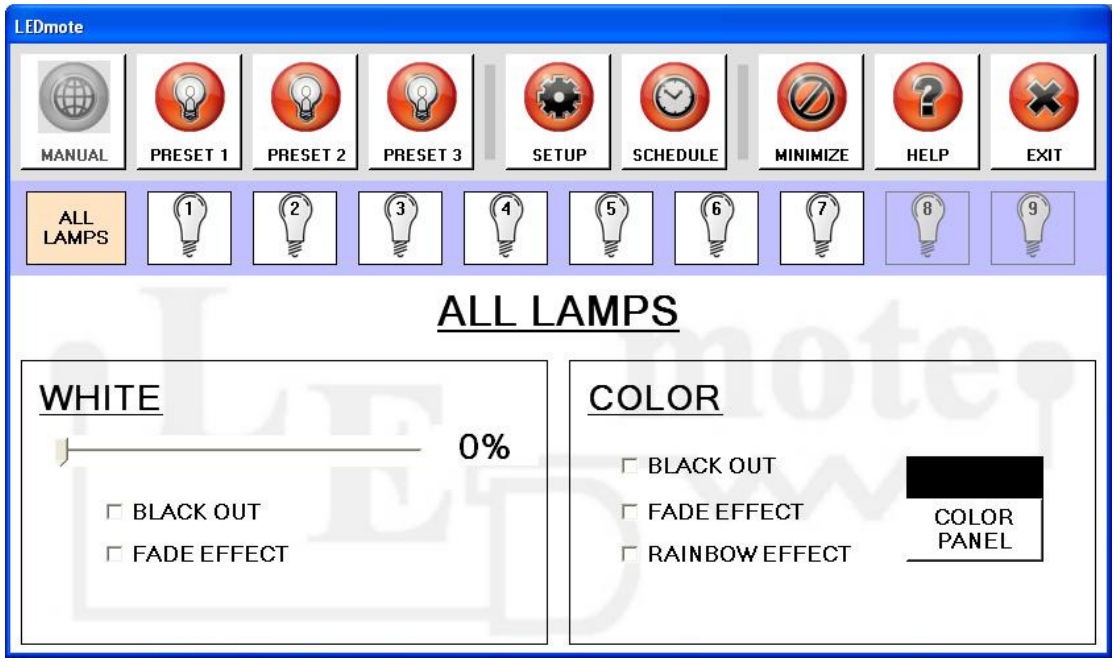
```
            Me.GroupMonthly.Visible = False
            Me.GroupWeekly.Visible = False
            Me.GroupYearly.Visible = True
        End If
    End Sub

End Class
```

10.4.3 Setup Screen




```
Imports System.Windows.Forms

Public Class Setup

    Private Sub OK_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles OK_Button.Click
        Me.DialogResult = System.Windows.Forms.DialogResult.OK
        Me.Close()
    End Sub

    Private Sub Cancel_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Cancel_Button.Click
        Me.DialogResult = System.Windows.Forms.DialogResult.Cancel
        Me.Close()
    End Sub

End Class
```

10.4.4 LEDmote Screen




```
Imports System.IO

Public Class LEDmoteControl
    Inherits System.Windows.Forms.Form

    Public Sub Setup_Screne()

        CurrentMode = "MANUAL"
        NewMode = "MANUAL"
        CurrentLamp = "ALL LAMPS"
        NewLamp = "ALL LAMPS"
        WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
        Me.BTN_PRESET1.Text = Preset1Name
        Me.BTN_PRESET2.Text = Preset2Name
        Me.BTN_PRESET3.Text = Preset3Name
        Change_Mode()
        Show_Number_Of_Lamps()
    End Sub

    Private Sub Show_Number_Of_Lamps()
```

```
Me.BTN_0.Enabled = False
Me.BTN_1.Enabled = False
Me.BTN_2.Enabled = False
Me.BTN_3.Enabled = False
Me.BTN_4.Enabled = False
Me.BTN_5.Enabled = False
Me.BTN_6.Enabled = False
Me.BTN_7.Enabled = False
Me.BTN_9.Enabled = False

Me.BTN_0.BackColor = System.Drawing.Color.Transparent
Me.BTN_1.BackColor = System.Drawing.Color.Transparent
Me.BTN_2.BackColor = System.Drawing.Color.Transparent
Me.BTN_3.BackColor = System.Drawing.Color.Transparent
Me.BTN_4.BackColor = System.Drawing.Color.Transparent
Me.BTN_5.BackColor = System.Drawing.Color.Transparent
Me.BTN_6.BackColor = System.Drawing.Color.Transparent
Me.BTN_7.BackColor = System.Drawing.Color.Transparent
Me.BTN_9.BackColor = System.Drawing.Color.Transparent

Me.BTN_0.ForeColor = System.Drawing.Color.Gray
Me.BTN_1.ForeColor = System.Drawing.Color.Gray
Me.BTN_2.ForeColor = System.Drawing.Color.Gray
Me.BTN_3.ForeColor = System.Drawing.Color.Gray
Me.BTN_4.ForeColor = System.Drawing.Color.Gray
Me.BTN_5.ForeColor = System.Drawing.Color.Gray
Me.BTN_6.ForeColor = System.Drawing.Color.Gray
Me.BTN_7.ForeColor = System.Drawing.Color.Gray
Me.BTN_9.ForeColor = System.Drawing.Color.Gray

If NumberOfLamps > 0 Then
    Me.BTN_0.Enabled = True
    Me.BTN_0.BackColor = System.Drawing.Color.White
    Me.BTN_0.ForeColor = System.Drawing.Color.Black
End If

If NumberOfLamps > 1 Then
    Me.BTN_1.Enabled = True
    Me.BTN_1.BackColor = System.Drawing.Color.White
    Me.BTN_1.ForeColor = System.Drawing.Color.Black
End If

If NumberOfLamps > 2 Then
    Me.BTN_2.Enabled = True
    Me.BTN_2.BackColor = System.Drawing.Color.White
    Me.BTN_2.ForeColor = System.Drawing.Color.Black
End If

If NumberOfLamps > 3 Then
    Me.BTN_3.Enabled = True
    Me.BTN_3.BackColor = System.Drawing.Color.White
```

```
        Me.BTN_3.ForeColor = System.Drawing.Color.Black
    End If

    If NumberOfLamps > 4 Then
        Me.BTN_4.Enabled = True
        Me.BTN_4.BackColor = System.Drawing.Color.White
        Me.BTN_4.ForeColor = System.Drawing.Color.Black
    End If

    If NumberOfLamps > 5 Then
        Me.BTN_5.Enabled = True
        Me.BTN_5.BackColor = System.Drawing.Color.White
        Me.BTN_5.ForeColor = System.Drawing.Color.Black
    End If

    If NumberOfLamps > 6 Then
        Me.BTN_6.Enabled = True
        Me.BTN_6.BackColor = System.Drawing.Color.White
        Me.BTN_6.ForeColor = System.Drawing.Color.Black
    End If

    If NumberOfLamps > 7 Then
        Me.BTN_7.Enabled = True
        Me.BTN_7.BackColor = System.Drawing.Color.White
        Me.BTN_7.ForeColor = System.Drawing.Color.Black
    End If

    If NumberOfLamps > 8 Then
        Me.BTN_9.Enabled = True
        Me.BTN_9.BackColor = System.Drawing.Color.White
        Me.BTN_9.ForeColor = System.Drawing.Color.Black
    End If

    Me.Refresh()

End Sub

Private Sub BTN_EXIT_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_EXIT.Click
    Call Save_Data()
    End
End Sub

Private Sub Save_Data()
    Dim x, y As Integer
    Dim textdelimiter As String

    ' Create an instance of StreamWriter to read from a file.

    Dim sw As StreamWriter = New StreamWriter(System.AppDomain.CurrentDomain.BaseDirectory & "data.txt")

    textdelimiter = "#"
```

```
        sw.Write(UserName & textdelimiter)
        sw.Write(Preset1Name & textdelimiter)
        sw.Write(Preset2Name & textdelimiter)
        sw.Write(Preset3Name & textdelimiter)
        sw.Write(MasterLampName & textdelimiter)

        For x = 0 To 8
            For y = 0 To 10
                sw.Write(Preset1Array(x, y) & textdelimiter)
            Next
            y = 0
        Next
        x = 0

        For x = 0 To 8
            For y = 0 To 10
                sw.Write(Preset2Array(x, y) & textdelimiter)
            Next
            y = 0
        Next
        x = 0


        For x = 0 To 8
            For y = 0 To 10
                sw.Write(Preset3Array(x, y) & textdelimiter)
            Next
            y = 0
        Next
        x = 0

        sw.Close()

    End Sub

    Private Sub BTN_MINIMIZE_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_MINIMIZE.Click
        Me.WindowState = FormWindowState.Minimized
    End Sub

    Private Sub WhiteBar_Scroll(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles WhiteBar.Scroll
        WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
        If CurrentLamp = "ALL LAMPS" Then
            CurrentArray(0, 1) = WhiteBar.Value
            CurrentArray(1, 1) = WhiteBar.Value
            CurrentArray(2, 1) = WhiteBar.Value
            CurrentArray(3, 1) = WhiteBar.Value
            CurrentArray(4, 1) = WhiteBar.Value
            CurrentArray(5, 1) = WhiteBar.Value
            CurrentArray(6, 1) = WhiteBar.Value
            CurrentArray(7, 1) = WhiteBar.Value
```

```
            CurrentArray(8, 1) = WhiteBar.Value
        Else
            CurrentArray(CurrentLamp, 1) = WhiteBar.Value
        End If
    End Sub

    Private Sub btnColorPanel_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles btnColorPanel.Click
        Dim i As Integer
        ColorDialog1.ShowDialog()
        If CurrentLamp = "ALL LAMPS" Then
            For i = 0 To 8
                CurrentArray(i, 3) = ColorDialog1.Color.R
                CurrentArray(i, 4) = ColorDialog1.Color.G
                CurrentArray(i, 5) = ColorDialog1.Color.B
                PictureBox1.BackColor     =     System.Drawing.Color.FromArgb(CType(CType(CurrentArray(0,     3),     Byte),     Integer),
CType(CType(CurrentArray(0, 4), Byte), Integer), CType(CType(CurrentArray(0, 5), Byte), Integer))
            Next
        Else
            CurrentArray(CurrentLamp, 3) = ColorDialog1.Color.R
            CurrentArray(CurrentLamp, 4) = ColorDialog1.Color.G
            CurrentArray(CurrentLamp, 5) = ColorDialog1.Color.B
            PictureBox1.BackColor    =    System.Drawing.Color.FromArgb(CType(CType(CurrentArray(CurrentLamp,    3),    Byte),    Integer),
CType(CType(CurrentArray(CurrentLamp, 4), Byte), Integer), CType(CType(CurrentArray(CurrentLamp, 5), Byte), Integer))
        End If

    End Sub

    Private Sub BTN_MANUAL_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_MANUAL.Click
        NewMode = "MANUAL"
        Call Change_Mode()
    End Sub

    Private Sub BTN_PRESET1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_PRESET1.Click
        NewMode = Preset1Name
        Call Change_Mode()
    End Sub

    Private Sub BTN_PRESET2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_PRESET2.Click
        NewMode = Preset2Name
        Call Change_Mode()
    End Sub

    Private Sub BTN_PRESET3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_PRESET3.Click
        NewMode = Preset3Name
        Call Change_Mode()
    End Sub

    Private Sub BTN_all_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_all.Click
        NewLamp = "ALL LAMPS"
        Call Change_Lamp()
    End Sub
```

```
Private Sub BTN_0_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_0.Click
    NewLamp = "0"
    Call Change_Lamp()
End Sub

Private Sub BTN_1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_1.Click
    NewLamp = "1"
    Call Change_Lamp()
End Sub

Private Sub BTN_2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_2.Click
    NewLamp = "2"
    Call Change_Lamp()
End Sub

Private Sub BTN_3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_3.Click
    NewLamp = "3"
    Call Change_Lamp()
End Sub

Private Sub BTN_4_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_4.Click
    NewLamp = "4"
    Call Change_Lamp()
End Sub

Private Sub BTN_5_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_5.Click
    NewLamp = "5"
    Call Change_Lamp()
End Sub

Private Sub BTN_6_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_6.Click
    NewLamp = "6"
    Call Change_Lamp()
End Sub

Private Sub BTN_7_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_7.Click
    NewLamp = "7"
    Call Change_Lamp()
End Sub

Private Sub BTN_8_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_9.Click
    NewLamp = "8"
    Call Change_Lamp()
End Sub
Private Sub Change_Mode()
    Select Case CurrentMode
        Case Preset1Name
            Preset1Array = CurrentArray
        Case Preset2Name
            Preset2Array = CurrentArray
        Case Preset3Name
```

```
                Preset3Array = CurrentArray
            Case Else
        End Select
        Select Case NewMode
            Case Preset1Name
                Me.BTN_PRESET1.Enabled = False
                Me.BTN_PRESET2.Enabled = True
                Me.BTN_PRESET3.Enabled = True
                Me.BTN_MANUAL.Enabled = True
                CurrentArray = Preset1Array
            Case Preset2Name
                Me.BTN_PRESET1.Enabled = True
                Me.BTN_PRESET2.Enabled = False
                Me.BTN_PRESET3.Enabled = True
                Me.BTN_MANUAL.Enabled = True
                CurrentArray = Preset2Array
            Case Preset3Name
                Me.BTN_PRESET1.Enabled = True
                Me.BTN_PRESET2.Enabled = True
                Me.BTN_PRESET3.Enabled = False
                Me.BTN_MANUAL.Enabled = True
                CurrentArray = Preset3Array
            Case "MANUAL"
                Me.BTN_PRESET1.Enabled = True
                Me.BTN_PRESET2.Enabled = True
                Me.BTN_PRESET3.Enabled = True
                Me.BTN_MANUAL.Enabled = False
        End Select
        CurrentMode = NewMode
        NewLamp = "ALL LAMPS"
        Call Change_Lamp()
        Me.Refresh()
    End Sub
    Private Sub Change_Lamp()
        If NewLamp = "ALL LAMPS" Then
            lblCurrentLamp.Text = "ALL LAMPS"
            WhiteBar.Value = CurrentArray(0, 1)
            WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
            chkBlackOutWhite.Checked = CurrentArray(0, 8)
            chkBlackOutColor.Checked = CurrentArray(0, 9)
            chkFadeWhite.Checked = CurrentArray(0, 6)
            chkFadeColor.Checked = CurrentArray(0, 7)
            chkRainbow.Checked = CurrentArray(0, 10)
            PictureBox1.BackColor     =     System.Drawing.Color.FromArgb(CType(CType(CurrentArray(0,     3),     Byte),     Integer),
CType(CType(CurrentArray(0, 4), Byte), Integer), CType(CType(CurrentArray(0, 5), Byte), Integer))
        Else
            lblCurrentLamp.Text = "LAMP " & NewLamp + 1
            WhiteBar.Value = CurrentArray(NewLamp, 1)
            WhiteIntensity.Text = ((WhiteBar.Value * 100) / 50) & "%"
            chkBlackOutWhite.Checked = CurrentArray(NewLamp, 8)
            chkBlackOutColor.Checked = CurrentArray(NewLamp, 9)
```

```
            chkFadeWhite.Checked = CurrentArray(NewLamp, 6)
            chkFadeColor.Checked = CurrentArray(NewLamp, 7)
            chkRainbow.Checked = CurrentArray(NewLamp, 10)
            PictureBox1.BackColor    =    System.Drawing.Color.FromArgb(CType(CType(CurrentArray(NewLamp,    3),    Byte),    Integer),
CType(CType(CurrentArray(NewLamp, 4), Byte), Integer), CType(CType(CurrentArray(NewLamp, 5), Byte), Integer))
        End If
        Select Case CurrentLamp
            Case "ALL LAMPS"
                BTN_all.BackColor = Color.White
            Case "0"
                BTN_0.BackColor = Color.White
            Case "1"
                BTN_1.BackColor = Color.White
            Case "2"
                BTN_2.BackColor = Color.White
            Case "3"
                BTN_3.BackColor = Color.White
            Case "4"
                BTN_4.BackColor = Color.White
            Case "5"
                BTN_5.BackColor = Color.White
            Case "6"
                BTN_6.BackColor = Color.White
            Case "7"
                BTN_7.BackColor = Color.White
            Case "8"
                BTN_9.BackColor = Color.White
        End Select
        Select Case NewLamp
            Case "ALL LAMPS"
                BTN_all.BackColor = Color.Bisque
            Case "0"
                BTN_0.BackColor = Color.Bisque
            Case "1"
                BTN_1.BackColor = Color.Bisque
            Case "2"
                BTN_2.BackColor = Color.Bisque
            Case "3"
                BTN_3.BackColor = Color.Bisque
            Case "4"
                BTN_4.BackColor = Color.Bisque
            Case "5"
                BTN_5.BackColor = Color.Bisque
            Case "6"
                BTN_6.BackColor = Color.Bisque
            Case "7"
                BTN_7.BackColor = Color.Bisque
            Case "8"
                BTN_9.BackColor = Color.Bisque
        End Select
        CurrentLamp = NewLamp
```

```
    Me.Refresh()
End Sub

Private Sub BTN_SETUP_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_SETUP.Click
    Setup.Preset1BtnName.Text = Preset1Name
    Setup.Preset2BtnName.Text = Preset2Name
    Setup.Preset3BtnName.Text = Preset3Name
    Setup.ShowDialog()
    If Setup.DialogResult = Windows.Forms.DialogResult.OK Then
        Preset1Name = Setup.Preset1BtnName.Text
        Preset2Name = Setup.Preset2BtnName.Text
        Preset3Name = Setup.Preset3BtnName.Text
        Me.BTN_PRESET1.Text = Strings.Left(Preset1Name, 9)
        Me.BTN_PRESET2.Text = Strings.Left(Preset2Name, 9)
        Me.BTN_PRESET3.Text = Strings.Left(Preset3Name, 9)
        Me.Refresh()
    End If
End Sub

Private Sub chkBlackOutWhite_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles chkBlackOutWhite.Click
    Dim i As Integer
    If CurrentLamp = "ALL LAMPS" Then
        For i = 0 To 8
            CurrentArray(i, 8) = chkBlackOutWhite.Checked
        Next
    Else
        CurrentArray(CurrentLamp, 8) = chkBlackOutWhite.Checked
    End If
End Sub


Private Sub chkBlackOutColor_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles chkBlackOutColor.Click
    Dim i As Integer
    If CurrentLamp = "ALL LAMPS" Then
        For i = 0 To 8
            CurrentArray(i, 9) = chkBlackOutColor.Checked
        Next
    Else
        CurrentArray(CurrentLamp, 9) = chkBlackOutColor.Checked
    End If
End Sub


Private Sub chkFadeColor_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles chkFadeColor.Click
    Dim i As Integer
    If CurrentLamp = "ALL LAMPS" Then
        For i = 0 To 8
            CurrentArray(i, 7) = chkFadeColor.Checked
        Next
    Else
        CurrentArray(CurrentLamp, 7) = chkFadeColor.Checked
```

```
    End If
End Sub


Private Sub chkFadeWhite_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles chkFadeWhite.Click
    Dim i As Integer
    If CurrentLamp = "ALL LAMPS" Then
        For i = 0 To 8
            CurrentArray(i, 6) = chkFadeWhite.Checked
        Next
    Else
        CurrentArray(CurrentLamp, 6) = chkFadeWhite.Checked
    End If
End Sub


Private Sub chkRainbow_Click(ByVal sender As Object, ByVal e As System.EventArgs) Handles chkRainbow.Click
    Dim i As Integer
    If CurrentLamp = "ALL LAMPS" Then
        For i = 0 To 8
            CurrentArray(i, 10) = chkRainbow.Checked
        Next
    Else
        CurrentArray(CurrentLamp, 10) = chkRainbow.Checked
    End If
End Sub

Private Sub BTN_SCHEDULE_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_SCHEDULE.Click
    Schedule.ShowDialog()
    If Schedule.DialogResult = Windows.Forms.DialogResult.OK Then
        If Schedule.Preset1.Checked = True Then
            ScheduleSetting = "Preset 1"
        ElseIf Schedule.Preset2.Checked = True Then
            ScheduleSetting = "Preset 2"
        ElseIf Schedule.Preset3.Checked = True Then
            ScheduleSetting = "Preset 3"
        Else
            ScheduleSetting = "Disabled"
        End If
        If Schedule.Disabled.Checked = False Then
            If Schedule.RecurrenceEnabled.Checked = False Then
                Recurrence = "None"
            Else
                If Schedule.Yearly.Checked = True Then
                    Recurrence = "Yearly"
                ElseIf Schedule.Weekly.Checked = True Then
                    Recurrence = "Weekly"
                ElseIf Schedule.Monthly.Checked = True Then
                    Recurrence = "Monthly"
                Else
                    Recurrence = "Daily"
```

```
                End If
            End If
            Call SetTimerLength()
        End If
    End If
End Sub

Private Sub ScheduleTimer_Elapsed(ByVal sender As Object, ByVal e As System.Timers.ElapsedEventArgs) Handles ScheduleTimer.Elapsed
    If TimerLength = 0 Then
        'Perform Timer Operation and Reset TimerLength
        If ScheduleSetting = "Preset 1" Then
            NewMode = Preset1Name
            Call Change_Mode()
        ElseIf ScheduleSetting = "Preset 2" Then
            NewMode = Preset2Name
            Call Change_Mode()
        ElseIf ScheduleSetting = "Preset 3" Then
            NewMode = Preset3Name
            Call Change_Mode()
        End If
        If Recurrence = "None" Then
        Else
            Call SetTimerLength()
        End If
    End If
    TimerLength = TimerLength - 1
End Sub

Private Sub SetTimerLength()
    Dim D1, D2, DTest As Date
    Dim DayOfWeek, DayOfMonth, MonthOfYear As Integer
    Dim Today As Boolean
    Dim EndLoop As Boolean
    Dim AddNumberOfMonths, AddNumberOfWeeks, AddNumberOfDays As Integer
    D1 = Now
    DTest = DateString & " " & Schedule.time1.Text & " " & Schedule.AMPM1.Text
    If DateDiff(DateInterval.Minute, D1, DTest) < 0 Then
        Today = False
    Else
        Today = True
    End If

    Select Case Recurrence
        Case "Daily"
            If Today = False Then
                D2 = DateValue(DateAdd(DateInterval.Day, 1, Now)) & " " & Schedule.time1.Text & " " & Schedule.AMPM1.Text
            Else
                D2 = DateString & " " & Schedule.time1.Text & " " & Schedule.AMPM1.Text
            End If
        Case "Weekly"
            AddNumberOfWeeks = 0
```

```
                AddNumberOfDays = 0
                EndLoop = False
                DayOfWeek = Weekday(Now, FirstDayOfWeek.Sunday)

                If Today = False Then
                    If DayOfWeek = 7 Then
                        DayOfWeek = 1
                        AddNumberOfWeeks = Schedule.NumericWeek.Value - 1
                    End If
                    DayOfWeek = DayOfWeek + 1
                    AddNumberOfDays = AddNumberOfDays + 1
                End If

                Do While EndLoop = False
                    Select Case DayOfWeek
                        Case 1
                            If Schedule.Sunday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 2
                            End If
                        Case 2
                            If Schedule.Monday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 3
                            End If
                        Case 3
                            If Schedule.Tuesday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 4
                            End If
                        Case 4
                            If Schedule.Wednesday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
```

```
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 5
                            End If
                        Case 5
                            If Schedule.Thursday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 6
                            End If
                        Case 6
                            If Schedule.Friday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                DayOfWeek = 7
                            End If
                        Case 7
                            If Schedule.Saturday.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.WeekOfYear, AddNumberOfWeeks, Now)) & " " & Schedule.time1.Text &
" " & Schedule.AMPM1.Text
                                D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                                EndLoop = True
                            Else
                                AddNumberOfDays = AddNumberOfDays + 1
                                AddNumberOfWeeks = Schedule.NumericWeek.Value - 1
                                DayOfWeek = 1
                            End If
                        Case Else
                            D2 = Now
                            EndLoop = True
                    End Select
                Loop
            Case "Monthly"
                AddNumberOfMonths = 0
                AddNumberOfDays = 0
                EndLoop = False
                DayOfMonth = DatePart(DateInterval.Day, Now)

                If Today = False Then
                    If DatePart(DateInterval.Month, Now) = 2 And DayOfMonth = 28 Then
                        DayOfMonth = 1
                        AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                    ElseIf DatePart(DateInterval.Month, Now) = 4 And DayOfMonth = 30 Then
```

```
                    DayOfMonth = 1
                    AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                ElseIf DatePart(DateInterval.Month, Now) = 6 And DayOfMonth = 30 Then
                    DayOfMonth = 1
                    AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                ElseIf DatePart(DateInterval.Month, Now) = 9 And DayOfMonth = 30 Then
                    DayOfMonth = 1
                    AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                ElseIf DatePart(DateInterval.Month, Now) = 11 And DayOfMonth = 30 Then
                    DayOfMonth = 1
                    AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                ElseIf DayOfMonth = 31 Then
                    DayOfMonth = 1
                    AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                End If
                DayOfMonth = DayOfMonth + 1
                AddNumberOfDays = AddNumberOfDays + 1
            End If

            Do While EndLoop = False
                Select Case DayOfMonth
                    Case 1
                        If Schedule.chk1.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 2
                        End If
                    Case 2
                        If Schedule.chk2.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 3
                        End If
                    Case 3
                        If Schedule.chk3.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 4
                        End If
```

```
                    Case 4
                        If Schedule.chk4.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 5
                        End If
                    Case 5
                        If Schedule.chk5.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 6
                        End If
                    Case 6
                        If Schedule.chk6.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 7
                        End If
                    Case 7
                        If Schedule.chk7.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 8
                        End If
                    Case 8
                        If Schedule.chk8.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 9
                        End If
                    Case 9
```

```
                If Schedule.chk9.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 10
                End If
            Case 10
                If Schedule.chk10.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 11
                End If
            Case 11
                If Schedule.chk11.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 12
                End If
            Case 12
                If Schedule.chk12.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 13
                End If
            Case 13
                If Schedule.chk13.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 14
                End If
            Case 14
                If Schedule.chk14.Checked = True Then
```

```
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 15
                End If
            Case 15
                If Schedule.chk3.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 16
                End If
            Case 16
                If Schedule.chk16.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 17
                End If
            Case 17
                If Schedule.chk17.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 18
                End If
            Case 18
                If Schedule.chk18.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 19
                End If
            Case 19
                If Schedule.chk19.Checked = True Then
```

```
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 20
                End If
            Case 20
                If Schedule.chk20.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 21
                End If
            Case 21
                If Schedule.chk21.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 22
                End If
            Case 22
                If Schedule.chk22.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 23
                End If
            Case 23
                If Schedule.chk23.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 24
                End If
            Case 24
                If Schedule.chk24.Checked = True Then
```

```
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 25
                End If
            Case 25
                If Schedule.chk25.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 26
                End If
            Case 26
                If Schedule.chk26.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 27
                End If
            Case 27
                If Schedule.chk27.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    DayOfMonth = 28
                End If
            Case 28
                If Schedule.chk28.Checked = True Then
                    D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                    D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                    EndLoop = True
                Else
                    AddNumberOfDays = AddNumberOfDays + 1
                    If DatePart(DateInterval.Month, Now) = 2 Then
                        DayOfMonth = 1
                        AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                    Else
                        DayOfMonth = 29
```

```
                            End If
                        End If
                    Case 29
                        If Schedule.chk29.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            DayOfMonth = 30
                        End If
                    Case 30
                        If Schedule.chk30.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            If DatePart(DateInterval.Month, Now) = 4 Or 6 Or 9 Or 11 Then
                                DayOfMonth = 1
                                AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                            Else
                                DayOfMonth = 31
                            End If
                        End If
                    Case 31
                        If Schedule.chk31.Checked = True Then
                            D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, Now)) & " " & Schedule.time1.Text & " "
& Schedule.AMPM1.Text
                            D2 = DateAdd(DateInterval.Day, AddNumberOfDays, D2)
                            EndLoop = True
                        Else
                            AddNumberOfDays = AddNumberOfDays + 1
                            AddNumberOfMonths = Schedule.NumericUpDown1.Value - 1
                            DayOfMonth = 1
                        End If
                    Case Else
                        D2 = Now
                        EndLoop = True
                End Select
            Loop
        Case "Yearly"
            DayOfMonth = DatePart(DateInterval.Day, Now)
            EndLoop = False
            MonthOfYear = DatePart(DateInterval.Month, Now)
            Dim MTest As Date
            AddNumberOfMonths = 0
            MTest = DatePart(DateInterval.Month, Now) & "/" & Schedule.NumericYearly.Value & "/" & DatePart(DateInterval.Year,
Now) & " " & Schedule.time1.Text & " " & Schedule.AMPM1.Text
```

```
                If DateDiff(DateInterval.Minute, D1, MTest) < 0 Then
                    AddNumberOfMonths = AddNumberOfMonths + 1
                    If MonthOfYear = 12 Then
                        MonthOfYear = 1
                    Else
                        MonthOfYear = MonthOfYear + 1
                    End If
                End If

                Do While EndLoop = False
                    Select Case MonthOfYear
                        Case 1
                            If Schedule.January.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 2
                            End If
                        Case 2
                            If Schedule.Feburary.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 3
                            End If
                        Case 3
                            If Schedule.March.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 4
                            End If
                        Case 4
                            If Schedule.April.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 5
                            End If
                        Case 5
                            If Schedule.May.Checked = True Then
```

```
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 6
                            End If
                        Case 6
                            If Schedule.June.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 7
                            End If
                        Case 7
                            If Schedule.July.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 8
                            End If
                        Case 8
                            If Schedule.August.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 9
                            End If
                        Case 9
                            If Schedule.September.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 10
                            End If
                        Case 10
                            If Schedule.October.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 11
```

```
                            End If
                        Case 11
                            If Schedule.November.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 12
                            End If
                        Case 12
                            If Schedule.December.Checked = True Then
                                D2 = DateValue(DateAdd(DateInterval.Month, AddNumberOfMonths, MTest)) & " " & Schedule.time1.Text & "
" & Schedule.AMPM1.Text
                                EndLoop = True
                            Else
                                AddNumberOfMonths = AddNumberOfMonths + 1
                                MonthOfYear = 1
                            End If
                        Case Else
                            D2 = Now
                            EndLoop = True
                    End Select
                Loop
            Case Else
                D2 = Schedule.Date1.Value & " " & Schedule.time1.Text & " " & Schedule.AMPM1.Text
        End Select

        TimerLength = DateDiff(DateInterval.Minute, D1, D2)

    End Sub

    Private Sub BTN_HELP_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles BTN_HELP.Click
        Help.Show()
    End Sub
End Class
```

10.5 PIC PWM Program

```
#include <p18f87j10.h>
#include <pwm.h>
#include <stdio.h>
#include <usart.h>


// CONSTANTS //
```

```
#define CLOCK_FREQ                  10000000
#define BAUD_RATE             19200
#define SPBRG_VAL             ( ((CLOCK_FREQ/BAUD_RATE)/16) -1)

#define POWER                               0x01
#define WHITE_UP                    0x02
#define WHITE_DOWN                          0x03
#define RED_UP                              0x04
#define RED_DOWN                    0x05
#define GREEN_UP                    0x06
#define GREEN_DOWN                          0x07
#define BLUE_UP                             0x08
#define BLUE_DOWN                   0x09
#define COLOR_UP                    0x0A
#define COLOR_DOWN                          0x0B

#define W_INITIAL                   700
#define C_INITIAL                   700

#define DC_MAX                              900
#define DC_MIN                              75

#define W_CHANGE                    75
#define R_CHANGE                    75
#define G_CHANGE                    75
#define B_CHANGE                    75


#define ConsoleIsPutReady()     (TXSTA1bits.TRMT)
#define ConsoleIsGetReady()     (PIR1bits.RC1IF)

typedef unsigned char BYTE;                 // 8-bit
// APPLICATION VARIABLES //

union
{
      struct
      {
            unsigned Power          : 1;
            unsigned None           : 7;
```

```
      } bits;
      unsigned char Value;
} PowerFlag;



// Function Prototypes
void HardwareInit( void );
void USARTInit( void );

void InterruptHandlerHigh( void );

void BT_Inquiry_CMD(void);

//MAIN //
void main()
{

// MISC Variable Definitions //
      char opcode;
      int i = 0;
      int j = 0;


// PWM Variable Definitions //
      unsigned char output_config;
      unsigned char output_mode;

      unsigned int pwm1_dc;
      unsigned int pwm2_dc;
      unsigned int pwm3_dc;
      unsigned int pwm4_dc;
      unsigned int pwm5_dc;

      char period;

      unsigned int power_status;



// USART Configuration
```

```
      USARTInit();

// Hardware Configurations
      HardwareInit();

      power_status = 0;

      TRISD = 0x00;
      PORTD = 0x01;


      while(1)
      {
            //CLRWDT();

            char inputstr[1];
            opcode = 0x00;
            gets1USART( inputstr, 1 );
            opcode = inputstr[0];

            switch( opcode )
            {
                  case POWER:
                        PORTDbits.RD7 ^= 1;
                        if( power_status == 0 )
                        {
                              power_status = 1;
                              // Set up the Period for the PWMs //
                              period = 0xFF;
                              OpenPWM1(period);                         // Sets the period for PMW1
                              OpenPWM2(period);
                              OpenPWM3(period);
                              OpenPWM4(period);
                              OpenPWM5(period);

                              // Extra Setup for Special PWM Registers ECCP1, ECCP2, ECCP3
                              SetOutputPWM1( SINGLE_OUT, PWM_MODE_1 );
//                            SetOutputPWM2( SINGLE_OUT, PWM_MODE_1 );
//                            SetOutputPWM3( SINGLE_OUT, PWM_MODE_1 );

                              // Reset duty cycle for PWMs
```

```
                pwm1_dc = C_INITIAL;
                pwm2_dc = C_INITIAL;
                pwm3_dc = C_INITIAL;
                pwm4_dc = W_INITIAL;
                pwm5_dc = W_INITIAL;

                // Set Duty Clcle for PWMs
                SetDCPWM4( pwm4_dc );          // White PWM
                SetDCPWM1( pwm1_dc );          // Red PWM
                SetDCPWM2( pwm2_dc );          // Green PWM
                SetDCPWM3( pwm3_dc );          // Blue PWM
                SetDCPWM5( pwm5_dc );          // Extra PWM
        }
        else if( power_status == 1 )
        {
                power_status = 0;
                PORTDbits.RD7 ^= 1;
                ClosePWM1();
                ClosePWM2();
                ClosePWM3();
                ClosePWM4();
                ClosePWM5();
        }
        break;
case WHITE_UP:    // WHITE UP
        PORTDbits.RD6 ^= 1;
        if( pwm5_dc >= DC_MAX );
        else
        {
                pwm5_dc = pwm5_dc + W_CHANGE;
                SetDCPWM5( pwm5_dc );
        }
        break;
case WHITE_DOWN:  // WHITE D0WN
        PORTDbits.RD6 ^= 1;
        if( pwm5_dc <= DC_MIN );
        else
        {
                pwm5_dc = pwm5_dc - W_CHANGE;
                SetDCPWM5( pwm5_dc );
        }
```

```
      break;
case RED_UP:      // RED UP
      PORTDbits.RD5 ^= 1;
      if( pwm1_dc >= DC_MAX );
      else
      {
            pwm1_dc = pwm1_dc + R_CHANGE;
            SetDCPWM1( pwm1_dc );
      }
      break;
case RED_DOWN:    // RED D0WN
      PORTDbits.RD5 ^= 1;
      if( pwm1_dc <= DC_MIN );
      else
      {
            pwm1_dc = pwm1_dc - R_CHANGE;
            SetDCPWM1( pwm1_dc );
      }
      break;
case GREEN_UP:    // GREEN UP
      PORTDbits.RD4 ^= 1;
      if( pwm2_dc >= DC_MAX );
      else
      {
            pwm2_dc = pwm2_dc - G_CHANGE;
            SetDCPWM2( pwm2_dc );
      }
      break;
case GREEN_DOWN:  // GREEN DOWN
      PORTDbits.RD4 ^= 1;
      if( pwm2_dc <= DC_MIN);
      else
      {
            pwm2_dc = pwm2_dc - G_CHANGE;
            SetDCPWM2( pwm2_dc );
      }
      break;
case BLUE_UP:     // BLUE UP
      PORTDbits.RD3 ^= 1;
      if( pwm3_dc >= DC_MAX );
      else
```

```
            {
                  pwm3_dc = pwm3_dc + B_CHANGE;
                  SetDCPWM3( pwm3_dc );
            }
            break;
      case BLUE_DOWN:   // BLUE DOWN
            PORTDbits.RD3 ^= 1;
            if( pwm3_dc <= DC_MIN );
            else
            {
                  pwm3_dc = pwm3_dc - B_CHANGE;
                  SetDCPWM3( pwm3_dc );
            }
            break;
      case COLOR_UP:    // COLOR UP
            PORTDbits.RD2 ^= 1;
            if( pwm1_dc >= DC_MAX );
            if( pwm2_dc >= DC_MAX );
            if( pwm3_dc >= DC_MAX );
            else
            {
                  pwm3_dc = pwm3_dc + B_CHANGE;
                  SetDCPWM3( pwm3_dc );
            }
            break;
      case COLOR_DOWN:  // COLOR DOWN
            PORTDbits.RD2 ^= 1;
            if( pwm3_dc <= DC_MIN );
            else
            {
                  pwm3_dc = pwm3_dc - B_CHANGE;
                  SetDCPWM3( pwm3_dc );
            }
            break;
      default:
            break;
}


if( PowerFlag.bits.Power == 1 )
{
```

```
                PowerFlag.bits.Power = 0;
                if( power_status == 0 )
                {
                      power_status = 1;
                      // Set up the Period for the PWMs //
                      period = 0x0F;
                      OpenPWM1(period);                          // Sets the period for PMW1
                      OpenPWM2(period);
                      OpenPWM3(period);
                      OpenPWM4(period);
                      OpenPWM5(period);

                      // Extra Setup for Special PWM Registers ECCP1, ECCP2, ECCP3
                      SetOutputPWM1( SINGLE_OUT, output_mode );
                      SetOutputPWM2( SINGLE_OUT, output_mode );
//                    SetOutputPWM3( SINGLE_OUT, output_mode );

                      // Reset duty cycle for PWMs
                      pwm1_dc = C_INITIAL;
                      pwm2_dc = C_INITIAL;
                      pwm3_dc = C_INITIAL;
                      pwm4_dc = W_INITIAL;
                      pwm5_dc = W_INITIAL;

                      // Set Duty Clcle for PWMs
                      SetDCPWM4( pwm4_dc );          // White PWM
                      SetDCPWM1( pwm1_dc );          // Red PWM
                      SetDCPWM2( pwm2_dc );          // Green PWM
                      SetDCPWM3( pwm3_dc );          // Blue PWM
                      SetDCPWM5( pwm5_dc );          // Extra PWM
                }
                else if( power_status == 1 )
                {
                      power_status = 0;
                      ClosePWM1();
                      ClosePWM2();
                      ClosePWM3();
                      ClosePWM4();
                      ClosePWM5();
                }
          } // end power flag if
```

```
	} // end while

}	// end main


#pragma code
#pragma interrupt InterruptHandlerHigh
void InterruptHandlerHigh ()
{
	// 0001 POWER FLAG
	if( !INTCON3bits.INT3IF & !INTCON3bits.INT2IF & !INTCON3bits.INT1IF & INTCONbits.INT0IF )
	{
		// Resent Flag Bits to 0
		INTCONbits.INT0IF = 0;
		INTCON3bits.INT1IF = 0;
		INTCON3bits.INT2IF = 0;
		INTCON3bits.INT3IF = 0;

		PowerFlag.bits.Power = 1;		// Set Power Flag
	}



//	if( INTCONbits.RBIF )
//	{
//		INTCONbits.RBIF = 0;
//		PowerFlag.bit.Power = 1;
//		INTCONbits.GIEH = 1;
//	}
}


void USARTInit( void )
{
/*
// Synchronous USART Setup
	TXSTA1.SYNC = 1;
	RCSTA1.SPEN = 1;
	TXSTA1.CSRC = 0;
```

L

```
      RCSTA1.CREN = 1;
*/

// Asynchronous USART Setup

      // Set BAUD Rate
      TXSTA1bits.BRGH = 0;
      BAUDCON1bits.BRG16 = 0;
      SPBRG1 = 0x07;

      TXSTA1bits.SYNC = 0;          // Set to Asynchronous
      RCSTA1bits.SPEN = 1;          // Set Serial Bit

      RCSTA1bits.RX9 = 0;                 // Nine/Eight bit mode

      RCSTA1bits.CREN = 1;          // Enable Reception

/*
      RCSTA1bits.SPEN = 1;          // Serial Port ENABLE bit
      TRISCbits.TRISC6 = 0;         // Sets RC6 to INPUT for TX (USART1)
      TRISCbits.TRISC7 = 1;         // Sets RC7 to OUTPUT for RX (USART1)

      TXSTA1 = 0x24;                      // Enables TXEN and BRGH HIGH
//    TXSTA1 = 0x20;                      // Enables TXEN and BRGH LOW

      RCSTA1 = 0x90;                      // Enables Serial Port & Continous Receive

      SPBRG = SPBRG_VAL;

      BAUDCON1 = 0x40;              // Enable REceive Operation is Idle
      */
}



void HardwareInit( void )
{

      CCP2CONbits.CCP2M2 = 0;
// Inturrupt Configuration Section //
```

```
      // Set Up Timer0
      TMR0H = 0;                  //clear timer
      TMR0L = 0;                  //clear timer
      T0CON = 0x82;               //set up timer0 - prescaler 1:8

      // Set Flag Bits to 0
      PowerFlag.Value = 0x00;

      // Disable Global Interrupts
      INTCONbits.GIEH = 0;
      INTCONbits.GIEL = 0;
      // Enable Priority Levels
      RCONbits.IPEN = 1;

      // INTERRUPT ENABLE BITS
//    INTCONbits.RBIE = 1;          // Interrupt On Change Enable bit RB7:4

      INTCON2bits.RBPU = 0;         // Disables all PORTB Pull-ups

      // INTERRUPT PRIORITY BITS
//    INTCON2bits.RBIP = 1;         // Interrupt on Change

      // Clear RB0, RB1, RB2, RB3 FLAGS
      INTCONbits.RBIF = 0;

      // Enables all HIGH priority inturrupts
      INTCONbits.GIEH = 1;
      // Enables all LOW priority peripheral interrupts
      INTCONbits.GIEL = 1;

      // Set RB0, RB1, RB2 to INPUTS
      PORTB = 0x00;
      TRISB = 0xF0;
//    LATB = 0x00;

}

// Bluetooth Inquiry Command //
void BT_Inquiry_CMD(void)
{
      Write1USART( 0x02 );
```

```
        Write1USART( 0x52 );
        Write1USART( 0x00 );
        Write1USART( 0x03 );
        Write1USART( 0x00 );
        Write1USART( 0x55 );
        Write1USART( 0x0A );
        Write1USART( 0x00 );
        Write1USART( 0x00 );
        Write1USART( 0x03 );
        return;
}
```